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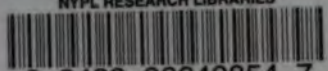
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A
PRACTICAL TREATISE
ON
HIGH PRESSURE
STEAM BOILERS

INCLUDING RESULTS OF
EXPERIMENTAL TESTS OF BOILER MATERIALS,

TOGETHER WITH
IMPROVED SAFETY APPARATUS, STEAM PUMPS, INJECTORS AND
ECONOMIZERS IN ACTUAL USE.

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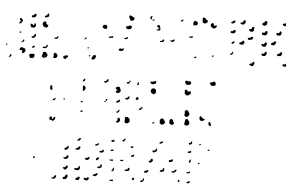


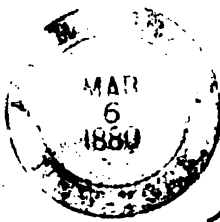
A
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INCLUDING RESULTS OF
RECENT EXPERIMENTAL TESTS OF BOILER MATERIALS,
TOGETHER WITH
A DESCRIPTION OF APPROVED SAFETY APPARATUS, STEAM PUMPS, INJECTORS AND
ECONOMIZERS IN ACTUAL USE.

BY
WILLIAM M. BARR

INDIANAPOLIS, IND.
YOHNN BROTHERS
1880.





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1879.

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P R E F A C E.

This book is not put forth so much as a specimen of book making as it is a record of notes, memoranda, experiments, practice, and experience gathered, during several years in which the writer has been connected in one way or another, with the design and manufacture of high pressure steam boilers.

No person at all acquainted with boilers would expect to receive at the hands of anybody an entirely original treatise on this subject. This book contains a considerable amount of practical information never before published, gleaned from the author's own experience, as well as valuable contributions from several of his friends, who have had large experience in boiler making.

The chapters on the strength of iron and steel have been carefully compiled from tests made with samples sheared from plates actually delivered for boilers under contract, and were not selected samples taken from the mill with a view to getting high results. The tables show that this country possesses materials for boiler construction having qualities which are not surpassed by any iron or steel in any market.

There is little doubt that the boiler of the future will be of steel, and considerable space has been given this material; many tests have been made, and records of the results appear, for the first time, in these pages.

This book comes far short of being what the writer would like to have it, many subjects of interest to boiler

makers and steam users have been omitted. Marine boiler have not been included, as that is a class of work which is under a more intelligent direction than generally found in the smaller shops, and have less need of such data as here furnished; to have included it, would have made a larger and more expensive book than the writer felt justified in undertaking. The same is also true in regard to locomotive boilers. Most of the smaller boiler shops are in charge of men who were once journeymen boiler makers, and "set up business on their own account." These persons are, as a class, good boiler makers, but having had little experience in estimating and designing work, other than the particular kind on which they have had a long experience, are often at a loss how to proceed; it is possible that this book may prove of service to many such.

The object has not been to make this a book specially for boiler makers, but a hand book for engine builders, architects, and steam users, as well.

The writer wishes to express his deep sense of obligation to his many friends who have contributed and assisted in the preparation of much of the data which appears in these pages, and especially to Mr. David Greig, Leeds, England, Mr. George H. Atkinson, Pittsburg, Penn., Mr. J. M. Allen, Hartford, Conn., Mr. Coleman Sellers, Philadelphia, Penn., and many others.

Free use has been made of recent papers read before engineering societies, and bearing on this subject; from which extracts have been made, and the proper credit given in the body of the work.

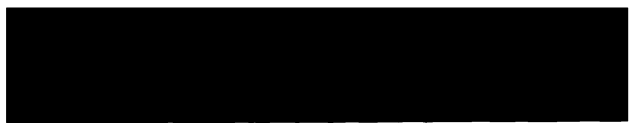
INDIANAPOLIS, IND., DECEMBER, 1879.

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ERRATA.

- Page 131. Eleventh line from the bottom, read *nearly* instead of clearly.
- Page 168. See foot note, giving correct titles to tables L and LI.
- Page 171. Tenth line from top, read *fues* instead of tubes.
- Page 257. Last line, read *originating* instead of originally.
- Page 305. Engraving. The foundation at E is shown under the dimension line Y. It should have been placed under the center line of the front. The error is in the engraving only; the figures are correct.
- Page 309. Thirteenth line from bottom, read *cleaning* instead of clearing.



occasionally as high as one hundred and fifty pounds. These high pressures are the result partly of experimental inquiry, but are mainly due to a better understanding of the principles of thermodynamics, for it is in accordance with its teachings that these higher pressures have been steadily adopted, so that now there is a very general tendency, arguing from pure theory, toward extreme pressures, under the belief that the highest economy is to be based upon, and is in fact, simply a question of pressure. This leads us to the conditions demanded in the construction of a steam generator, which are,

Safety while working under high pressures.

Simple in construction.

Thorough circulation of water in all parts of the boiler.

Economical in the use of fuel.

Durability in service.

Facility of examination, cleaning and repairs.

The first requisite in a boiler would seem to be that of safety, for without this all the other conditions are of little value. By safety is meant that pressure of steam which a boiler can generate and hold without danger of rupture.

The safety of a boiler depends upon its form; the materials of which it is made; and the details of its construction. The conditions of safety and durability depend largely upon the selection of a suitable material—one which shall have considerable hardness, and at the same time, a high tensile strength combined with a reasonable degree of toughness.

Practically, the only available materials for the construction of steam generators are—cast iron, wrought iron and steel. Each of these have properties which are of value in this connection, though most of the steam boilers now in use are made of wrought iron. Formerly, copper had been used in boiler construction, especially for fire boxes for locomotives, and the internal heating surfaces in

marine boilers. This material has been almost entirely abandoned in boiler construction, notwithstanding its superior conducting power over iron or steel; the causes which have led to its abandonment are high first cost, inferiority in hardness and tensile strength as compared with the other materials named.

The materials of construction hold such an important place in boiler design that some space should be given in a work of this kind to the consideration of the crude and finished iron employed in boiler making. Before any steam generator can be properly designed there must be a knowledge of the properties of the materials which are to enter into its construction; and as castings, wrought iron and steel, have one common starting point, it will not be thought out of place to give in brief outline the foreign elements which are contained in and which give character to iron and steel. The crude cast iron as it comes from the blast furnace, no matter what impurities it may contain, is known under the name of *pig iron*. These are usually classed as either white or gray irons; and it is probable that the difference in the qualities, or properties, leading to this classification are due more to the influence of the contained carbon than to any other cause. The white iron approaches more nearly the character of an alloy than the gray iron, which partakes more of the nature of a mechanical mixture. The latter iron is employed for foundry use, the former for the manufacture of wrought iron. The principal impurities in pig iron are sulphur, silicon, phosphorus, manganese, carbon.

Sulphur is almost always found in pig iron and has a remarkable influence on its quality. White irons appear to contain more of it than the gray varieties. At low heats it will in a measure prevent fluidity in cast iron, causing it to assume a mushy appearance, which may be entirely overcome by the application of a higher heat, when the

mushy appearance changes to that of a more perfect fluid. Sulphur diminishes the strength of castings in a very high degree by causing them to be cold-short, brittle and hard.

Silicon is always present in crude as well as in refined irons, being next after carbon the commonest impurity met with in iron. When in combination with crude iron, the proportion is usually found to be greater in the gray than in the white varieties. Quantities as small as one-half of one per cent causes crude iron to be brittle, and its presence in castings is regarded as injurious to quality, the best castings being those which contain it in the least amount.

Phosphorus has the effect to harden cast iron, and to increase its fusibility. It enters into chemical union with iron and is present in quantities rarely exceeding one to one and a quarter per cent in ordinary white or gray irons. In combination with iron it renders it close and compact, and has the tendency to make it cold-short when reduced to low temperatures or near the freezing point. Pig iron containing phosphorus melts easily, becomes very fluid, is easily managed in refining, and when contained in wrought iron up to a limit of one-fourth of one per cent has no perceptible effect on its welding power, except that it requires it to be done at a low heat.

Manganese, in its chemical properties, is in many respects like iron, and will form similar compounds. These two metals have an affinity for each other, and during the operation of reducing the iron from the ore they enter into such an intimate relation as to form an alloy. Manganese causes iron to be more fluid when melted, and to be hard and brittle when cold. White iron contains more manganese than gray irons. Some ores yield an iron containing as much as ten and twelve per cent of manganese, which has the property of containing in its composition as much as one-twenty-fifth of its weight of carbon in a state

of chemical combination; this iron is extensively used in steel making by the Bessemer process, and is generally known by its German name, *speigel-eisen*.

Carbon is always present in pig iron. The quantity so found is variable, and its effect on the character of the iron is by no means certain. Sometimes it appears to be a chemical union, when it then partakes somewhat of the nature of an alloy. At other times it seems to have no affinity for the iron, and its presence in a free state in the pores, or rather between the crystals of the iron, is regarded as little else than a mechanical mixture. These differences are not altogether due to the quantity of carbon present, but rather to its state, or particular form of combination.

Iron, when pure, is soft and malleable. Carbon adds to its hardness, renders it more brittle and lowers the degree of fusibility when a sufficient quantity of carbon is present to make what is known as cast iron. In this state it can neither be forged nor welded.

The quantity of carbon in pig iron commonly ranges from one and one-half to three and one-half per cent.

How carbon enters into combination with iron can hardly be said to have been satisfactorily explained. It is certain, however, that a small quantity of carbon has a very marked effect upon a large mass of iron.

The state in which carbon is present in cast iron may be determined,

1. By the appearance of the fracture.
2. By dissolving a portion of the iron in either diluted sulphuric or muriatic acids.

The former of the two is generally employed in determining the approximate quality of pig iron and castings.

By the latter method there is more certainty in arriving at the actual condition of the contained carbon. The acid acting upon the iron, but not upon the carbon, the latter

is left in a free state in the solution, if it so exists in the sample tested. After dissolving gray irons, the solution will contain numerous black particles, which have all the properties of ordinary graphite. A white iron known to have more carbon in its composition than the gray, when similarly dissolved will present fewer particles of carbon in the free state, because the contained carbon is in a chemical combination with the iron and is present in the solution as a carbide; thus presenting fewer particles of graphite or carbon than the former solution.

White cast iron—So far as observed, this seems to have all the qualities of a perfect alloy; that is, the mixture of carbon and iron produces a metal having the different properties from the materials which enter into its composition.* It is harder than gray iron, or any iron in which the carbon is present in a state of mechanical mixture only. The fracture of white iron presents a surface of silvery whiteness, with but little luster, showing little or no free carbon. It is extremely hard, will resist the action of the file or chisel; it is very brittle, and is unfit for any of the uses to which ordinary castings are applied. It melts at a lower heat than gray iron, but does not become liquid at this low temperature, assuming, rather, a pasty condition, which may be overcome by the application of a still higher temperature.

Mottled cast iron contains about the same quantity of carbon as the white and gray varieties. The condition in which it is held is about half combined and half in a free state. It is very hard, brittle and not so elastic as gray iron.

Gray cast iron is made from the pig irons in which there is the least carbon chemically combined, and the greater

* Carbon being a *non-metallic* substance, it will be understood that the use of the word alloy in this sentence is unconventional, its use being applied to mixtures of *metals* only.

portion in the free state, as graphite. A general average would show about one per cent of carbon chemically combined and about two and one-half per cent of free graphite.

Foundry pig is usually sold in the market as either Nos. one, two, three, No. 1 being the softest and No. 3 the hardest. No. 1 is usually of a dark gray color, having large granular crystals, between which particles of carbon are seen and may be easily detached. In melting it becomes quite fluid and accurately fills the mold in which it is poured. It is not so hard or so strong as either of the other two irons named, and to make the best castings, portions of the "heat" should be made up of the lower grades. No. 2 pig-iron is harder and has a finer grain than No. 1, owing to more of the carbon being in a combined and less in the free state. When properly mixed with No. 1 it makes the best castings for machinery or for any use in which strength and durability are required. No. 3 iron is not in general suitable for castings which require working in the machine shop. It is hard, brittle and is suitable only for mixing with higher grades of iron in the production of heavy castings.

Chilled iron is produced by a change in the condition of the carbon present in the cast iron from a state of mechanical mixture to that of chemical combination, brought about chiefly by a sudden cooling while in a molten state. When pig iron is melted, or in a fluid state, it is not improbable that the carbon which was present in a free state in the pores of the iron is dissolved and unites with the iron. In ordinary cooling the carbon would separate from the iron as in the pig iron before melting, but when the fluid iron is suddenly cooled the carbon is condensed by the contraction of the iron and forced to remain in chemical union with it, instead of disengaging itself and collecting in the pores of the casting.

CHAPTER II.

CAST IRON AS A MATERIAL FOR STEAM BOILERS.

Arguments in Favor of It—Objections to its Use—Effect of the Impurities found in Cast Iron—Tensile Strength of Cast Iron—Elastic Limit of Cast Iron—Defects in Castings—Behavior of Cast Iron in the Fire—On Designing Cast Iron Boilers.

Cast iron as a material for boilers—The arguments in favor of cast iron as a material for steam generators and which must of necessity be confined to sectional boilers, are,

1. That the transmission of heat through plates of an equal thickness of cast or wrought iron is in favor of the former.

2. That in point of durability it excels wrought iron, for the following reasons:

- a. It will resist corrosion better than wrought iron.
- b. It is unaffected by the chemical impurities of feed water or the acids found in the products of combustion.
- c. On account of its granular structure it is not possible for it to blister when subjected to a high heat in the furnace.
- d. It is not liable to be strained by inequality of temperature.

3. As the parts must of necessity be small, they are capable of resisting very high pressures and are not dependent on any system of stays or braces for strength.

4. Its low first cost, together with the certainty that any number of parts can be made exact duplicates of each

other, and the facility with which these parts can be fitted not only for original use but to replace defective or worn out sections.

5. A defective section replaced by a new one renders a cast iron boiler as good as new, which is claimed as a very great advantage over wrought iron boilers, as a patch can never equal in strength the original plate.

Objections—The objections urged against cast iron as a material for steam boilers are,

1. That it is an unsuitable material, in consequence of its treacherous nature when subjected to high or unequal temperatures.

2. That the cooling strains in the manufacture often produce flaws or other defects in the castings which are hidden to the eye and do not become apparent by merely testing them by hydraulic pressure, and which may, without a moment's warning, lead to a sudden and disastrous fracture.

3. Cast iron seldom gives warning by any of the indications of weakness which characterize or precede the failure of wrought iron.

4. Cast iron being a crude product, there is no certainty that castings can be made uniform in strength or in other qualities.

5. Cast iron boilers are objected to on account of deficient circulation due to their construction, and especially to the fact that they must be made in small pieces; that there is difficulty in getting the steam generated into the steam room of the boiler, without priming; but this is a question of design rather than one of material—yet, as the material can only be used in certain sizes and forms, the objection is entitled to consideration.

The arguments here presented both for and against cast iron as a material for steam boilers are, in the main, those

offered by engineers and boiler makers when addressing actual or prospective purchasers.

The reasons given for the rejection of cast iron as a material for steam boilers will doubtless be observed to be miscellaneous rather than specific. An inquiry into the relative properties of cast iron and wrought iron ought but does not show why the latter is preferred to the former material. Scarcely any two mines furnish iron ore of the same composition and it is doubtful whether any two furnaces make an iron having precisely the same qualities. From this it will readily be understood why there may be some difficulty in making castings possessing certain qualities in the same degree. This latter, it may be said, is not absolutely essential to safety so long as the castings are sound and strong.

The impurities usually found in cast iron and which give it character are, sulphur, which renders iron *hot-short*, silicon or phosphorus, rendering it *cold-short*, and carbon, which gives to it its fusibility. The degree of hardness or softness of castings depends somewhat, but not entirely, upon the quantity of carbon contained in its composition. The carbon present in hard and brittle castings is often chemically combined with the iron; while soft and tough castings contain perhaps the same percentage of carbon mechanically combined. The selection of iron for the foundry is a very important one, but can not be entered into here. The selection, however, must be such that castings shall possess moderate hardness, closeness of grain, strength and toughness.

A comparison of the properties of cast and wrought iron will show that ordinary castings have sufficient strength for boilers, so that it is not on this account, but because of its unsatisfactory behavior in the furnace at a high temperature that has had most to do with its rejection.

From a mean of many experiments it may be said that ordinary castings have a tensile strength of about fifteen thousand pounds per square inch, or 6.69 gross tons. When special care has been exercised in the selection and mixture of pig iron, castings may be made of a higher tensile strength, and tests show that a strength of twelve to fifteen tons per square inch may be obtained. This, however, should be regarded as a maximum attainment and does not refer to ordinary castings, nor especially to thin cored work required in the sections for cast iron boilers.

The elastic limit of cast iron varies somewhat, but is not far from one-third of its breaking strain. This would give five thousand pounds per square inch as the utmost limit of safety in common castings. Allowing a factor of safety for cast iron boilers of ten, a working pressure would then be allowed of .223 ton or five hundred pounds per square inch of section. This would give for sections three-eighths inch thick a safe working pressure of one hundred and eighty-eight pounds per square inch. If it were a question of strength merely, this would be quite sufficient to meet every case in ordinary practice. But every experienced foundryman knows that castings can not be relied upon with any degree of certainty. Fractures in cooling are likely to occur at any point where two surfaces join each other at right angles. If they differ in thickness, or if the two pieces are of any considerable size, this is almost sure to be the case. Blow holes are so frequently found in castings that their presence is generally admitted in all ordinary work; as they are mostly below the surface there is no determining where they are located, to what extent they exist, or in what direction they lead. In addition to this, the process of cooling in the mold after the casting is made, introduces a class of abnormal strains which are brought about by the cooling or fixing of one portion of a casting over that of another.

These strains are of a very complex character and frequently of themselves will distort if not fracture the piece containing them. Annealing is frequently resorted to in order to counteract or neutralize these strains. In large castings slow cooling is practised as much as possible, the effect of which is to develop a coarse, uneven grain, being finest near the surface and growing coarser and more irregular toward the center. Where pieces join each other, cavities are likely to occur by reason of the irregular grouping of the crystals, which is one of the principal causes of these irregular strains.

After a casting has been poured and consolidation begun, then, the more rapidly it can be safely cooled, the finer and more even will be the grain, and for any given metal the greater will be its strength. The cooling, in order to obtain the best results, should be uniform throughout the mass. To attain this, it may be necessary to uncover some of the thicker portions of the casting. If the cooling be unequal and at the same time quite rapid, injurious strains are brought into action which may have the effect, as already stated, to fracture the casting at a weaker point.

The quality of cast iron may be judged somewhat by the appearance of the surface of fracture while still fresh. Soft and tough castings are coarser grained and have a less silvery luster than very hard castings. The judging of the quality of castings at sight can only be acquired by experience.

Cast iron in the fire—The effects of intense heat on castings is to melt off all sharp projections and those parts necessary to the bolting of the pieces together. The metal almost invariably changes from the bright, granular appearance characteristic of good castings, to very coarse, uneven grains, having scarcely any metallic luster. It becomes

extremely brittle and is so unlike its former state that it is utterly unfit for further use in the foundry in the production of castings requiring strength.

The continued heating and reheating of any metal would in time destroy it, but cast iron seems to be less able to withstand the effects of severe heat and repeated cooling than wrought iron. So far, the behavior of cast iron in the fire has been anything but satisfactory and at present it meets with but little favor among engineers as a material for steam boilers. That form has much to do with its durability and safety ought to be admitted.

The only cast iron boiler which has had an extended sale in this country is that designed by the late Joseph Harrison, Jr., and for many years manufactured by him at his works in Philadelphia. Mr. Harrison was an accomplished and successful engineer, who gave many years of valuable time in improving the details of this boiler and conducting experiments on a large scale, which, fortunately, his abundant means enabled him to do. It is probable that any suggestion calculated to make this boiler a success had at least an intelligent and impartial trial. Notwithstanding all this, the boiler can not be said to have ever become popular.


During the autumn of 1878, a gentleman contracted, through the writer, for a wrought iron boiler, to replace a Harrison boiler, which had for thirteen years previously furnished the steam for driving the machinery of his mill. He stated that during this time the boiler worked to his satisfaction.

There are other examples which go to show that when suitable irons are employed, and the boiler properly designed and cared for when in use, cast iron may be used in the construction of steam boilers. The essential requisites seem to be, that pieces be small and free from angular projections, or changes of direction if these by any means

necessitate an increase of thickness at the line of juncture. The castings should be of uniform thickness throughout and contain no external bolting flanges, or other projections, in the fire.

Where boilers are made wholly of cast iron and subject to internal or bursting strains, the sections should be, preferably, as nearly spherical as possible, and should in no case have flat surfaces of any considerable extent forming either the outside or inside of a boiler. Every section in a cast iron boiler must be strong enough to withstand the pressure of steam without any system of bracing, or stays of any kind, except those necessary to the bolting of the parts together to make a complete boiler.

In the construction of boilers partly of wrought and partly of cast iron, the strains upon the latter should be those of compression rather than those of extension.



CHAPTER III.

WROUGHT IRON AS A MATERIAL FOR STEAM BOILERS.

Tenacity and Ductility of Iron—Properties of Iron, as Modified by Working—Welding—Texture of Wrought Iron—Effect of Cinder in Iron—Elasticity—Elastic Limit—Malleability—Flexure—Defects in Boiler Plates—Varieties of Plate Iron—Tests of Boiler Plate—Homogeneous Iron.

Wrought iron is prepared, usually, from the harder varieties of pig iron, by a succession of processes such as refining, boiling or puddling, squeezing, hammering, rolling, etc.; the primary object being to rid the iron of all the foreign substances contained in it which are calculated to reduce its strength and malleability, and, secondly, to prepare it in convenient size and shape for manufacturers' use.

Wrought iron has for many years past been the principal material employed in the construction of steam generators of whatever kind. It has many qualities which make it a very desirable material for the purpose. That quality of boiler plate is judged to be the best which has the greater tensile strength, combined with ductility and malleability. These properties are affected in some measure by the impurities existing in the pig iron from which the plate iron is made, as well as the subsequent working the iron receives before being rolled out into plates.

It is impossible to eliminate all the impurities in cast iron during its conversion into wrought iron. The following table gives the chemical analysis of a sample of boiler plate having a tensile strength of fifty-five thousand pounds per square inch :

Iron.....	99.20
Carbon.....	.04
Manganese.....	.17
Silicon.....	.15
Sulphur.....	.03
Phosphorus.....	.21
Oxygen.....	.20
	<hr/> 100.00

The above iron contained, and is included in the above analysis, 0.80 per cent of cinder. The noticeable thing in any analysis of wrought iron is the small percentage of contained carbon. In order to show how nearly the impurities in pig iron are removed during the process of conversion, the chemical analysis of an average sample of white iron is given below, by which a comparison is easily instituted:

Iron.....	89.44
Carbon, (Combined.....	2.45
Free.....	.87
Manganese.....	2.71
Silicon.....	1.11
Sulphur.....	2.51
Phosphorus.....	.91
	<hr/> 100.00

Wrought irons should possess in a good degree the following properties:

Tenacity.	Welding power.
Ductility.	

Each of these properties are influenced in some measure by the impurities in the iron, which may produce the following defects:

Cold-short iron is very brittle when cold, cracking badly, or breaking if bent at a sharp angle or doubled; but may be forged and welded at a high heat. This defect

occurs in irons which have an excess of phosphorus. *Red-short*, or *hot-short* iron, may be tenacious when cold, but easily broken when hot; it welds with great difficulty, though tough and reliable when taken directly from the bar and used cold. Red shortness occurs in iron containing an excess of sulphur.

Tenacity is that property in a material by which it resists a force which tends to separate or tear it asunder. This is a very important property in irons intended for steam boilers. The tensile strength of American boiler plate will range from forty thousand to sixty thousand pounds per square inch. Unless portions of the plates have been actually tested or the plates are known to have been made from blooms of the very best quality, it is not safe to assume a greater tensile strength than forty-five thousand pounds per square inch of section. This applies to such irons only as are stamped by reputable makers as C. H. No. 1, and higher grades; these latter are usually designated by some private brand or trade mark. Some of these special irons are stamped and guaranteed sixty thousand pounds.

Boiler plates may possess high tensile strength at the expense of other qualities, such as homogeneousness and toughness. There are manufacturers of boiler plate who press doubts as to whether an iron suitable for steam boilers can be made having all the necessary qualities and at the same time possess a tensile strength greater than forty-five thousand pounds per square inch. They assert that the iron becomes harder and more brittle as the tensile strength increases, and that the properties of hardness and brittleness introduced into the sheets by far outweigh the advantages which may be gained by the increased tensile strength.

Toughness is an invaluable property in boiler plate, and means a combination of qualities, such as hardness, tenacity and ductility, by which the material is better enabled to withstand the effects of irregular strains, and fractures induced by concussion or bulging.

Ductility is that property which a material possesses—like iron, for example—of being drawn out without breaking. This elongation is produced by subjecting the iron to a tensile stress higher than the elastic limit when a permanent change of form takes place. It is found that tenacity has more influence upon the ductility of metals than malleability. We are thus led to expect that there will be something in common between the tensile strength and ductility of wrought iron. This will be affected somewhat by the quality of the original bar and the treatment it receives by subsequent working.

The following table* shows the effect produced by different modes of working, changes of temperature, etc. The conclusions given are founded upon a large number of experiments by Mr. Kirkaldy and others:

TABLE I.
ON THE PROPERTIES OF IRON, AS MODIFIED BY WORKING.

	TENSILE STRENGTH.	DUCTILITY.
Reducing diameter by rolling.....	Increased.....	Reduced.
Turning or removing the skin.....	No alteration.....	No alteration.
Reducing diameter by forging.....	Increased.....	Reduced.
Annealing.....	Reduced.....	Increased.
Welding.....	{ Reduced from between 4.1 and 43.8 per cent. }	Reduced.

* From "Notes on Building Construction," Rivington's London, 1879.

TABLE 1—CONTINUED.

	TENSILE STRENGTH.	DUCTILITY.
Stress suddenly applied.....	Reduced 18.5 per cent.....	Reduced in nearly all cases.
Additional Hammering	Increased.....	Reduced.
Hardening in water or oil.....	Increased.....	Reduced.
Cold rolling—plates.....	Doubled.....	Destroyed.
Cold rolling—bars.....	Increased 50 per cent.....	Reduced 60 per cent.
Galvanizing.....	No difference.....	
Effect of frost, 23° F.....	Reduced 2.3 per cent.....	Reduced 8 per cent.
Effect of frost, stress suddenly applied.....	Reduced 3.6 per cent.....	Reduced between 0 and 30 per cent.

Texture of wrought iron—Irons are usually said to be in texture either fibrous or granular. When wrought iron has been forged under a hammer directly from a bloom the forging presents a granular or jagged grain; this grain is not uniform in size in large forgings, being coarser in the center and finest near the surface. If the process of hammering be continued, it will become, when reduced to smaller bars, uniformly fine grained. If, however, instead of this continued hammering, the original forged billet be run through a train of rolls the texture will have changed from granular to fibrous. M. Janoyer in a paper on the texture of iron* maintains that iron presents but a single texture, and that is the granular one; all others are only metamorphoses of this, due to defective temperature at the moment of finishing, which does not permit complete welding of the entire mass. He suggests classifying wrought iron into welded, non-welded and imperfectly welded irons, instead of fibrous and granular. When iron is pure and homogeneous its texture is granular. The operation of puddling consists in stirring a mass of spongy iron in the midst of a bath of

*Journal Franklin Institute, vol. 68.

cinder, which prevents the intimate approximation of its particles. This opposes a thorough welding of the mass and favors the production of a fibrous texture; since during the subsequent working, the molecules can slide over each other, thus giving to the iron its fibrous appearance.

The temperature at which iron is rolled has much to do with determining its texture: for example, if two or more bars of crude granular iron be laid one above the other to form a *fatot*, and this *fatot* be raised to a welding heat and passed through a set of rolls, the result will be granular iron, if the welding temperature be maintained; if, however, the temperature falls below the welding point the texture will then be fibrous instead of granular, because of the unequal temperature of the bar, which permits the molecules or particles of the iron to slide over each other during the process of rolling.

Cinder.—All wrought irons contain more or less cinder in their composition, and the fibrous texture of iron may almost always be traced to its presence, especially when worked in the rolls at too low a temperature. The presence of cinder always prevents perfect welding. Squeezing the blooms as they come from the puddling furnace will remove a considerable portion of the cinder, but all blooms intended for boiler plates should be worked under a heavy steam hammer until all the cinder is worked out of it, if such a thing is possible. The presence of the cinder, oxide of iron, or any other substance between the surfaces of the two plates of iron will prevent their welding; these foreign substances between plates are the cause of blisters in boiler plates, by preventing perfect welding.

Malleability is that property by which bodies may be drawn out by forging or hammering. Soft and fibrous are more malleable than hard or granular irons.

Boiler plates seldom require reducing in thickness, or otherwise wrought, except at joints in which three or more plates intersect. Any iron at all suitable for boilers will possess this property in a sufficient degree.

Flexure—A very important property in iron for boiler plates is that of flexure, or bending. In every act of bending or flanging boiler plate there are two forces to be overcome:

1. The extension of the metal on the outside of the curve.
2. The compression of the metal on the inside.

As might be expected, thoroughly welded or granular irons bend easier than fibrous. Boiler plates which will stand flanging or bending to a right angle both with and against the grain when heated to a cherry red, and without cracking or breaking in the curve, will be found suitable for any ordinary boiler work. The lower grades of iron will scarcely stand such a test, except at a high heat and for narrow widths.

The defects in iron boiler plates are principally imperfect welding, brittleness and low ductility, all of which may be largely overcome by a proper selection of materials in the earlier stages of its manufacture and by a careful manipulation during the successive operations of reheating, welding, and especially by a thorough working under a heavy steam hammer.

Ordinarily, the selection of particular brands of iron for the manufacture of boiler plate is entirely beyond the control of the persons who are to use the iron. Hence, irons of this class are usually guaranteed by the makers to be of a certain tensile strength. This is usually satisfactory to purchasers, on the general belief that if the specimen tested has an average tensile strength of, say, fifty thousand pounds per square inch of section, it possesses the other qualities

needed for a good boiler plate not requiring flanging, and in this manner for plates required for any service.

Varieties of plate iron—The wrought iron plates now regularly offered in the market are known as either C.—C. No. 1 or C. H.—C. H. No. 1—and C. H. No. 1 flange.

C. IRON, or charcoal iron, is the common boiled or puddled iron, rolled into bars or plates. This grade of iron is porous, and will become very brittle with repeated heating and cooling. It will not stretch much before breaking and will break suddenly. Its tensile strength ranges usually from thirty to forty thousand pounds per square inch. It is only suited for tank work, and ought never to enter into any portion of boiler construction.

C. No. 1 IRON, or C. H. iron (charcoal hammered, as it is oftener known), is the same iron as the above, except that it is subjected to more careful working and is hammered into suitable blooms before rolling. This iron very much resembles the common iron in its general qualities, having but little elasticity and breaking with a sudden jerk. Like the above, it becomes very brittle by repeated heating and cooling, though somewhat stronger than C. iron; its tensile strength ranging from thirty-five to forty-five thousand pounds per square inch. It is not a suitable iron for boiler construction.

C. H. No. 1 SHELL IRON is made from C. H. blooms, with the addition of selected scrap, the whole being thoroughly welded under a heavy steam hammer and afterward rolled into plates. This iron, like the two others just described, is injuriously affected by repeated heating and cooling, which has the effect to render it brittle. This is the quality of plate generally used in the construction of land boilers using pressures of steam below eighty or ninety pounds

per square inch. It rarely enters into the construction of boilers for river or ocean service; its principal defect being a lack of homogeneity and imperfect welding. Its tensile strength is from forty to fifty thousand pounds per square inch.

Shell irons are often made of a much better quality and higher tensile strength than the above, when ordered for any particular purpose. The following table gives the mechanical tests to which ten samples were subjected, and which were taken from boiler plates rolled for river steamboat service; five samples from Phillips, Nimick & Co., and five from Lloyd, Son & Co., both firms manufacturing at Pittsburg, Pa. The tests were made by Mr. George H. Atkinson, inspector of steam boilers at that point, the testing machine used being the design of Rehlie Brothers and of the kind furnished the United States government.

TABLE II.

TENSILE STRENGTH OF C. H. No. 1 BOILER PLATE.

SAMPLE.		BREAK- ING WEIGHT.	TENSILE STRENGTH PER SQUARE INCH.	ELONGA- TION IN PARTS OF AN INCH.	TIME CONSUMED IN TEST, IN MINUTES AND SECONDS.	WEIGHT ON MA- CHINE AT WHICH ELONGA- TION COM- MENCED.	REMARKS.
THICK- NESS.	WIDTH.						
.25	.96	18,000	75,000	.125	MIN. SEC. 4.30	14,500	Stamped Phil- lips, Nimick & Co., C. H. No. 1, 57,000. Short speci- men.
.26	1.00	17,600	67,692	.1875	4.09	14,500	
.25	1.00	17,000	68,000	.1875	4.00	14,000	
.26	1.00	18,600	71,538	.1875	5.00	15,000	
.26	.90	16,800	71,794	.1875	3.30	14,000	
.24	1.00	14,900	62,083	.1875	4.00	13,600	Stamped Lloyd, Son & Co., Pittsburg, 57,000. Short specimen.
.24	1.00	14,700	61,250	.125	4.00	13,500	
.24	1.00	13,800	57,500	.1875	3.30	12,400	
.24	1.00	13,900	57,916	.1875	4.00	13,000	
.24	1.00	14,200	59,166	.1875	3.30	12,500	

C. H. No. 1 FLANGE IRON is similar to the above, the difference being that only the very best scrap iron and charcoal hammered blooms are used. The greatest care is exercised in the selection of materials, and the working in the forge is such as to insure thorough welding. In texture it is less fibrous and more granular than any of the irons preceding it. On account of its nearer approach to a homogeneous structure, it is less liable to blister or crack in the fire. It will stand repeated heating and cooling, and should have good flanging qualities. The tensile strength should never fall below fifty thousand pounds per square inch, and does not often exceed sixty-five thousand pounds. The elastic limit will vary from eighteen thousand to twenty-five thousand pounds per square inch, and will stretch from twenty-five to thirty per cent in ordinary two inch specimens. This is the highest grade of iron regularly offered in the market and is quite extensively used in the construction of marine boilers and for the heads and other flange plates of land boilers.

Plates of this quality of iron are usually branded with the name of the maker and the guaranteed tensile strength; thus:

SMITH, JONES & CO.
C. H. No. 1 FLANGE.
57,000

This method of stamping was introduced in order to meet the requirements of the government regulations with reference to the quality of plates entering into steam boilers intended for use on board steam vessels in the United States. The pressure of steam allowed to be carried is determined upon the shape of the boiler and the tensile strength of the material; hence the figures stamped upon the plates ought always be below the actual tensile strength of the plates bearing them. A sample sheared from several plates bearing the stamp of the makers and intended for

steamboat boiler service were taken to the Custom House, Pittsburg, Pa. and tested by Mr. Atkinson, with results as given below:

TABLE III.

TENSILE STRENGTH OF PHILLIPS, NIMICK & CO., C. H. NO. 1 FLANGE IRON.
57,000.

SAMPLE.		BREAK- ING WEIGHT.	TENSILE STRENGTH PER SQUARE INCH.	ELONGA- TION IN PARTS OF AN INCH	TIME CONSUMED IN TEST, IN MINUTES AND SECONDS.	WEIGHT ON THE MACHINE AT WHICH ELONGA- TION COM- MENCED.	REMARKS.
THICK- NESS.	WIDTH.						
.26	1.00	20,600	79,230	.1875	5.00	16,500	Short specimen.
.26	1.00	16,700	64,230	.1875	3.30	14,500	U. S. regulation
.25	1.00	19,300	77,200	.1875	4.00	16,000	
.25	1.00	19,900	79,600	.1875	4.30	16,500	

The writer was shown at the works at Phillips, Nimick & Co., Pittsburg, Pa., another grade of flange iron named by them SLIGO C. H. NO. 1 FLANGE, which was guaranteed sixty thousand pounds tensile strength at its lowest limit. Specimens of both hot and cold flanging shown at their works attest the superior quality of this brand of iron. Its tensile strength, as given by them, was from sixty thousand to sixty-five thousand pounds per square inch, with an elastic limit of from twenty thousand to twenty-two thousand pounds and a stretch of twenty-eight to thirty per cent. Samples of this iron, taken from plates rolled for a boiler intended for a western steamboat and tested by Mr. Atkinson, gave results as follows:

TABLE IV.

TENSILE STRENGTH OF PLATES STAMPED, PHILLIPS, NIMICK & CO. C. H.
No. 1, SLIGO, 60,000.

SAMPLE.		BREAK- ING WEIGHT.	TENSILE STRENGTH PER SQUARE INCH.	ELONGA- TION IN PARTS OF AN INCH.	TIME CONSUMED IN TEST, IN MINUTES AND SECONDS.	WEIGHT ON THE MACHINE AT WHICH ELONGA- TION COM- MENCED.	REMARKS.
THICK- NESS.	WIDTH.						
.23	1.00	14,800	64,347	.1875	MIN. SEC. 3.00	13,000	Short specimen U. S. regula- tion.
.23	1.00	16,200	70,434	.1875	3.30	14,000	
.23	1.00	15,600	67,826	.1875	3.30	14,000	
.31	.80	16,100	64,919	.1875	4.00	15,400	
.24	1.00	15,700	65,416	.25	3.30	13,500	
.28	.86	16,600	68,936	.1875	4.00	14,500	

This firm make another and higher grade of iron which they call SLIGO SPECIAL. It is a high grade of flange iron, specially adapted for the construction of all kinds of steam boiler work. This iron will stand working into any shape in which it is possible to work iron, and the makers claim that its qualities are improved by repeated heating and cooling, an assertion borne out by exhibiting specimens which had many times been reheated and cooled and then doubling the plate cold. The guaranteed tensile strength was given at from sixty-two thousand to sixty-eight thousand pounds per square inch, with an elastic limit of twenty-five thousand to twenty-eight thousand pounds and a stretch of from thirty to thirty-three per cent.

Another grade of iron is manufactured by them called SLIGO FIRE BOX IRON, having qualities the same as the preceding iron, and a tensile strength from sixty-four thousand to seventy thousand pounds per square inch and elastic limit from twenty-eight thousand to thirty thousand pounds, with a stretch from thirty to thirty-three per cent.

These irons are free from anything like brittleness, are tough and have a homogeneous granular texture, with occasional fibers of silky luster in bending fracture. The writer regrets that he was not able to obtain at this time samples from plates rolled to order, that special tests might be made. The figures given above are those resulting from tests made by the company in their laboratory upon a Rehlle Brothers' testing machine, for their own guidance in its manufacture.

Homogeneous iron or (as it is oftener called) mild steel, is a somewhat recent term, used to designate a wrought iron of uniform granular texture throughout its mass; it is not necessarily to be considered as purer than other wrought irons and may contain in some degree most, if not all, the elements usually considered as impurities in pig iron. The term *homogeneous* in this connection simply implies that the iron is of the same kind or of the same nature throughout the plate. It should be entirely free from cinder, as it would be impossible to make a homogeneous iron with cinder in its composition, for the reason that it has no affinity for and being of an entirely different nature from iron, will not combine with it; the presence of cinder in any iron prevents contact or perfect welding, by keeping the molecules of iron asunder and is one of the reasons for the fibrous character of ordinary wrought bar and plate irons.

Homogeneous iron can best be made by a suitable preparation of the iron by either the Bessemer or Siemens-Martin process, or by melting wrought iron in crucibles and then casting into a solid ingot, from which the plates or bars may afterwards be made.

This material is known in the market under the names of *homogeneous iron*, *mild steel* and *homogeneous steel*. The name of *ingot iron* has also been proposed. The latter is,

perhaps, more nearly correct than the three former and is probable will come into general use in time. As it does not sensibly harden unless it contains at least 0.30 per cent of carbon, it would appear that the use of the term steel is scarcely allowable. At present, however, the question among boiler makers is, broadly, Iron *vs.* Steel, and in order to keep the two separate the term *steel* will be used in this book to designate the particular material just described, though homogeneous or ingot iron is, as already said, more nearly correct.

CHAPTER IV.

STEEL AS A MATERIAL FOR STEAM BOILERS.

Faults of the Earlier Steel Plates—Qualities in Steel which Recommend it as a Material for Boilers—Its Nature must be Studied—The Defects of Steel—Homogeneous Plates—Impurities which Affect the Quality of Plates—Tensile Strength of Steel Plates—Crucible Steel Plates—Bessemer Steel Plates—Open Hearth Steel Plates.

Steel is usually spoken of as an intermediate metal between wrought and cast iron, its position being determined by the quantity of carbon contained in its composition. For the higher grades of steel this may be true, but as the quantity of carbon in steel boiler plates is often less than is found in samples of wrought iron, this definition, then, is defective. The difference between steel and wrought iron does not consist entirely in the quantity of carbon contained in the former over the latter, but rather that steel has been *melted* and cast into a malleable ingot, which is an entirely different thing from puddling and one in which the quantity of carbon contained in it has nothing to do, especially when present in very small quantities, as in mild or very soft steels. When there is carbon enough in steel to cause hardening when suddenly cooled, it then plays an important part in its quality and imparts to it properties which are not wanted in boiler plates, but which are valuable in steel intended for tools and other purposes.

Steel is characterized by a fine granular texture, and when the contained carbon amounts to 0.40 to 0.50 per cent, it has the property of hardening and taking a tem-

per. There are several varieties of steel, differing in strength, hardness and ductility. The particular quality of steel best suited for boiler plate contains from 0.12 to 0.20 per cent of carbon, or so little carbon as to permit a red heat and sudden quenching, without destroying the property of flexure. A higher percentage of carbon increases the tensile strength, at a loss of ductility.

The advantages of steel as a material for boilers were recognized many years ago and was so employed to a moderate extent.

A leading article in *Engineering*, 1878, says: "It was not till about fifteen years ago, when plates of Bessemer steel were offered to the makers in quantities, that the use of steel for boiler making can be said to have become fairly established. Even up to the present day its use to any considerable extent for stationary boilers has been confined, with few and unimportant exceptions, to some half-dozen boiler works in the Manchester district, but these are of the very highest standing. Only two of these, however, have used steel extensively for shells, the rest having contented themselves by using it chiefly for the furnace tubes. Bessemer steel plates have been used for boilers of various kinds by upwards of fifty other makers in different parts of the kingdom, but as a rule against the advice of these makers, and (shall we say consequently?) often with unsatisfactory results." "For marine boilers, steel plates have been used only to a very limited extent. Of forty of the best known firms of marine engine builders, including those who make for the Admiralty, up to a very recent date only about half a dozen had used steel plates and half of these would not have used them if they had had their own way."

The steel furnished in this country, as well as that made abroad during most of this time, not possessing the properties required to make its employment a success, fell into dis-

favor and has been for along time under a cloud; many manufacturing establishments well known to the writer declining to have anything to do with it—others employed it because contracts called for it, but with the understanding there should be no recourse for damage in case of failure. No doubt this has had much to do with the little attention given to the production of a reliable steel boiler plate. At this time, however, a marked change is observed in manufacturers and users alike. There is a growing demand for steel boilers, not only in this country, but in Europe. From the present outlook it seems almost certain that the boiler of the future will be of steel.

Steel as a material for steam boilers recommends itself on account of its homogeneity, tensile strength, malleability, ductility, freedom from laminations and blisters. It requires greater care in working than is usually given to iron. It is a higher material and requires a higher intelligence to properly work it. This intelligence means a knowledge of the properties and peculiarities of the material. Steel differs so much from wrought iron that in order to work it properly its nature must be studied and understood. To demand that it shall conform to all the ordinary practice of working wrought iron is absurd. If it can do so, well; if not, then the method of working must conform to the nature of the material. Steel is not a material of definite quality and its properties vary with each change of quality. It can be made almost as hard as a diamond, certainly hard enough to cut glass. There is no substance known which equals in elasticity a good steel watch spring. It is possessed of a toughness which is unapproached by any other kind of metal; it has strength in all directions and before it breaks it will yield even to fifty per cent. It may be hardened, tempered or annealed at will. During these processes the material is studied and is worked in such manner as is best

suiting to its quality. No one thinks of subjecting bar iron and bar steel to the same treatment in the forge or workshop. It is not unlikely that many failures in steel boiler plates have arisen from the want of this very precaution at the outset. A steel plate was used just as an iron plate, and because it failed under such treatment the material was condemned as untrustworthy and dangerous—a sweeping verdict, which can come only of impatience, carelessness or ignorance.

There is no doubt that many of the earlier faults in steel were due to imperfections in manufacture or imprudent handling and cooling after rolling. But now that plates are carefully made and annealed after shearing to dimensions, the burden of the responsibility rests largely upon the boiler maker.

Quoting again from *Engineering* the writer sums up his review of steel for boilers as follows:

“That of some eighty boiler makers who have fairly tried steel plates, only some eight or nine can be said to have persevered with its use and used it extensively; that where the use of steel plates has been persevered in against the advice and feeling of the boiler maker, the result has generally been unsatisfactory; that it may be taken for granted that the prejudice on the part of boiler makers against the use of steel is, as a rule, inversely proportionate to the extent of their acquaintance with it. It would appear that those makers who have not been alive to the difference required in the working and treatment of iron and steel, or who have gone timidly to work and let the workman find out for themselves the best way to treat steel, have usually had trouble and have only been too glad to receive a confirmation of their adverse opinion.”

The defects in boiler plates—For steel, the principle defects are brittleness, low ductility, and flaws induced by

the presence of cavities formed by bubbles of air or gas in the original ingot. The two former may partially be overcome by a still further removal of the foreign substances which affect the softness of steel and by reducing it to a more nearly pure iron. The latter is not so easily overcome; it is doubtful whether a cavity once formed by a bubble of air or gas in the body of an ingot can ever be welded by subsequent hammering or working of any sort, owing to the interior surface of the cavity being lined with a film of oxide which may be brought into close surface contact, but not welded. Such a cavity, flattened down during the process of hammering and rolling into a mere surface contact, must be regarded as an incipient fracture, which may at any time spread to almost any extent and in any direction, when the conditions are such as to induce it. The harder the steel the greater the certainty of such extension of fracture; this tendency is diminished as softness and ductility are increased.

In steel plates ductility is a property of very great importance, for without it plates are liable to give way without any of the usual indications of failure or even a moment's warning. Other things being equal, ductility increases in this material as its tensile strength is diminished. It is only in homogeneous irons or *mild* steels, as they are usually called, which possess this property in the highest degree, and these are not usually made having a tensile strength higher than about seventy thousand pounds per square inch; a reduction to sixty thousand or even fifty-five thousand pounds will be found to be still more ductile. Some experiments by Mr. Charles Huston on American steels exhibited the following results:

(4)

TABLE V.

	TENSILE STRENGTH.	CONTRACTION OF AREA, PER CENT.
Crucible steel (not quite hard enough to temper).....	78,366	28.66
Crucible steel (ordinarily soft).....	64,000	36.33
Siemens-Martin steel (exceptionally soft).....	54,600	47.

The increase in ductility, in proportion to the decrease in tensile strength, is quite marked.

There is a limit to the amount of ductility which can be given homogeneous plates, arising from the practical difficulty in the manufacture of solid ingots. This difficulty is not entirely confined to mild steels, though the ingots are apt to be more spongy in a soft and ductile metal than in the harder varieties.

This fact has engaged the attention of steel makers for some years and plans for compressing the fluid steel have been suggested by several prominent manufacturers, among whom are Sir Henry Bessemer and Sir Joseph Whitworth. The latter subjects the molten steel to a pressure of some six tons per square inch, by which all cavities are closed up, the gases contained in them driven out, the metal being compressed to about seven-eighths of its original bulk, its density and strength being greatly increased. Owing to the great cost of compressing steel by either of the above methods, it can not be at present adopted in the commercial production of boiler plate.

The writer saw at the Edgar Thompson steel works, what is now their regular practice, the compression of steel ingots by steam. After pouring the ingot a cap is placed over the top of the mould and securely fastened by a key, making a steam tight joint. A flexible tube leads from this cap to a conveniently arranged steam pipe. A pressure of about seventy-five pounds of steam is used in compress-

ing the fluid ingot, and has given very satisfactory results. The absence of anything calculated to impair the quality of the ingot is a valuable feature in the process.

Homogeneous steel plates are expected to possess in a good degree, tenacity and ductility, and to be more nearly equal in these properties when tested both lengthwise and across the grain than is usual in fibrous wrought iron plates.

In Mr. Kirkaldy's tests of Krupp's and Yorkshire iron plates, the differences in tensile strength were found to be as follows:

LENGTHWISE OF THE GRAIN.

Krupp—Stress per square inch of fractured area.....	85,144 lbs.
Yorkshire—Stress per square inch of fractured area.....	61,140 lbs.

ACROSS THE GRAIN.

Krupp—Stress per square inch of fractured area.....	65,359 lbs.
Yorkshire—Stress per square inch of fractured area.....	54,110 lbs.

These specimens were unannealed. The figures show an average of nine specimens of Krupp's iron and an average of eighteen of the Yorkshire iron.

It will be observed that in Krupp's iron the difference in tensile strength, when taken in the two directions, stands 85,144 to 65,359, or the iron is 30.3 per cent stronger in the direction of the fiber than across it. And similarly the Yorkshire iron has an increased strength of thirteen per cent in the direction of the fiber over that taken from across the plate.

Mr. Kirkaldy made some tests of the Landore-Siemens steel for the English Admiralty in 1875, in which it was shown to be a remarkably homogeneous metal, with results as follows: Unannealed plates, 0.37 inch thick, 10 inches between supports, ultimate strength per square inch length-

wise of grain, 72,878 pounds; ultimate strength per square inch across the grain, 72,670 pounds; or a difference of only .00286 per cent, showing it to be much superior in this particular property than either of the two former irons.

A homogeneous steel plate will be a doubtful gain if secured at the expense of even a partial loss of ductility over the very best iron plates now manufactured.

One of the principal faults of a homogeneous plate is its liability to fracture from very slight surface or edge imperfections when under high tension—imperfections which would scarcely, if ever, affect a fibrous iron plate. In such a case the stronger steel plate would obviously be inferior to an iron plate, not in strength, but in trustworthiness. A fracture once begun in a homogeneous plate will extend from the edge into the body of the plate if that be the direction of least resistance. In this respect it is almost the very opposite of iron, which usually confines its fractures to the line of rivet holes, or if in the body of the plate the fracture usually follows the direction of the fiber slowly and does not extend in the rapid manner in which it is apt to do in a steel plate.

So far as correcting mere fractures in a plate are concerned much can be said in favor of a fibrous over a homogeneous material. It is not an uncommon practice where fractures are discovered in iron plates to stop its extension by simply drilling a hole at the end of the fracture and inserting a rivet—the fractures often being repaired without removing the plate.

There is little doubt that a homogeneous plate will resist strains which induce fracture much longer than iron plates of the same thickness, but once the fracture is started a homogeneous plate will allow its extension in a shorter time and to a greater extent than a tough fibrous plate would. Still, with all its drawbacks, a good tough

homogeneous metal of reasonable tensile strength and high ductility is, all things considered, the best material that can be selected for boiler construction.

The ordinary impurities which affect the quality of steel are phosphorus, sulphur and silicon.

Phosphorus renders steel cold-short, and as boiler plates are usually worked cold, the less there is of it in the plates the better. The highest allowable limit in good steel boiler plate is 0.08 per cent and should not exceed 0.05 or 0.06 per cent if possible; it having no perceptible effect on plates at that percentage.

Sulphur renders steel hot-short and thus affects the working in the steel works rather than in the boiler shop, except in flange plates. Sulphur should not exceed 0.05 per cent in steel boiler plates and even at this percentage the plates should contain at least 0.25 of manganese in order to counteract the hot-short effects of the sulphur.

Silicon in steel boiler plate, even in small quantities, renders it hard and decreases its ductility. It ought not to exceed 0.05 per cent in any steel intended for steam boilers.

Copper is sometimes found in steel and when present in any appreciable quantity renders steel hot-short and has a marked effect upon its welding properties when present in quantities exceeding 0.03 to 0.05 per cent.

The effect of carbon in steel is to increase its hardness and to decrease its fusibility and welding power.

The following table shows the effect of different quantities of carbon in steel and iron :

TABLE VI.
SHOWING THE CHARACTERISTICS OF IRON AND STEEL FOR DIFFERENT
PROPORTIONS OF CONTAINED CARBON.
(*Bauermann's Metallurgy*).

NAME.	PERCENTAGE OF CARBON.	PROPERTIES.
1. Malleable iron*	0.25	Is not sensibly hardened by sudden cooling
2. Steely iron.....	0.35	Can be slightly hardened by quenching.
3. Steel	0.50	Gives sparks with a flint, when hardened.
4. Steel	1.00 to 1.50	Limits of steel of maximum hardness and tenacity
5. Steel	1.75	Superior limit of welding steel.
6. Steel	1.80	Very hard cast steel, forging with great difficulty.
7. Steel	1.90	Not malleable hot.
8. Cast iron.....	2.00	Lower limits of cast iron, can not be hammered.
9. Cast iron.....	6.00	Highest carburized compound obtainable.

The percentage of carbon in the above table is greatly in excess of that used in the manufacture of boiler plate; the quantities in actual use for this grade of metal may be found in the analyses of the different samples of steel as given in this chapter.

Tensile strength of steel boiler steel—This is a subject on which opinions have, in the past, widely differed. There is little doubt that the earlier steel boiler plates were made of too high tensile strength and too little ductility. At present most English engineers require that the plates shall in no case exceed twenty-nine tons (64,960 lbs.) per square inch. It is found, however, that steel with a strength of twenty-six tons (58,240 lbs.) per square inch will weld better and with more certainty than steel of a higher strength. A mild steel is more easily worked and less likely to be injured by careless handling than steel of high grade, and if it can be kept as low

*Wrought iron, not malleable cast iron.

as sixty thousand pounds tensile strength per square inch, preserving ductility and toughness, it will be amply strong and will meet every ordinary requirement in boiler construction.

Requirements of steel plates entering into the construction of steam boilers made under the supervision of Lloyd's Register of British and Foreign Shipping:

1. "The material to have an ultimate tensile strength of not less than twenty-six tons (58,240 lbs.) and not more than thirty tons (67,200 lbs.) per square inch of section.

2. "A strip cut from every plate used in the construction of the furnaces and combustion chambers and strips cut from other plates taken indiscriminately, heated uniformly to a low cherry red heat and quenched in water of 82° Fahrenheit, must stand bending to a curve of which the inner radius is not greater than one and a half times the thickness of the plates tested.

3. "All the holes to be drilled, or if they be punched the plates to be afterwards annealed.

4. "All plates, except those that are in compression, that are dished or flanged, or in any way worked in the fire, to be annealed after the operations are completed.

5. "The boilers upon completion to be tested in the presence of one of the society's engineer surveyors, to not less than twice the intended working pressure."

The three competing steels now in this market are crucible steel, Bessemer steel and the Siemens-Martin steel. The latter is oftener known as Open Hearth steel.

These are to be regarded as distinguishing *processes* rather than three different kinds of steel, as they do not necessarily produce a material having chemical or mechanical properties widely differing from one another.

Crucible steel boiler plate—The practice of Park, Brother & Co., Pittsburg, Pennsylvania, in the manufacture of cru-

cible steel boiler plate, is to select a suitable wrought iron, one which shall be as low in carbon and as free from impurities as possible. These bars are cut up into short pieces and are afterwards packed in crucibles containing a charge of about eighty pounds each. These crucibles also contain a very small quantity of charcoal, just enough to render the iron fluid, so that it may be poured from the crucible into an ingot mould. These ingots are then rolled into plates.

The testing of the plates in the mill consists in shearing off a strip an inch or more in width, heating it to redness and plunging it into water, allowing it to remain there until cold; the sample is then bent over double and hammered down with a sledge or steam hammer, until the surfaces touch, as shown in the engraving, figure I.



FIGURE I.

If the steel will stand this test without showing any signs of fracture it "passes inspection" and is then sheared to the sizes required for the market. Should the sample show a fracture or crack in bending, the whole plate is rejected as being unfit for steam boilers.

A difficulty in the manufacture of crucible steel plate is to keep down its tensile strength. This requires great care in its manufacture, for if the tensile strength is too low the plates are apt to be soft or spongy in some places and harder in others; this, of course, would not be a homogeneous material and would, in consequence, be unfit for boiler making.

The lowest practical limit of crucible cast steel boiler plate is about sixty thousand pounds tensile strength; the maximum tensile strength should not greatly exceed

seventy-five thousand pounds. Crucible steel ranging in tensile strength from sixty-five thousand to seventy thousand pounds and having ductility enough to elongate eighteen to twenty per cent on a two inch specimen, has been found to be a good steel in practice. Park, Brother & Co. have succeeded in making a sixty thousand T. S. steel which elongated thirty per cent in a two inch specimen. The amount of carbon in the sample tested was 0.16 per cent; another sample containing 0.27 per cent of carbon elongated twenty-five per cent in a two inch specimen and stood a tensile strength of seventy-five thousand pounds.

The quality of crucible steel boiler plate depends more upon the quantity of carbon contained in its composition than upon any other element. The following analysis by Park, Brother & Co. shows the composition of their standard seventy thousand pound boiler plate:

Carbon (combined).....	0.3010
Carbon (graphite).....	none
Silicon.....	0.0492
Phosphorus.....	0.0298
Sulphur.....	0.0163
Manganese.....	0.0643
Iron (by difference).....	99.5394
	<hr/>
	100.0000

The following analysis of the same grade of metal from the same firm, was made at the Midvale Steel Works, Nicetown, Pa., by R. Kent and H. G. DeBrunner:

AVERAGE OF SIX ANALYSIS.

Park, Brother & Co., Homogeneous Boiler Plate, Seventy Thousand Pounds.

Carbon (combined).....	0.28
Carbon (graphite).....	none
Silicon.....	0.05
Phosphorus.....	0.03

Sulphur	0.02
Manganese.....	0.10
Iron (by difference).....	99.52
	<u>100.00</u>

Analysis of Park, Brother & Co., homogeneous boiler plate, seventy thousand pounds tensile strength, as determined at the School of Mines, Stockholm, Sweden :

Carbon	0.290
Silicon.....	0.040
Phosphorus.....	0.033
Sulphur	0.015
Manganese	0.050
	<u>.428</u>
[Iron, by difference.....	99.572]
	<u>100.000</u>

The mechanical tests given below are by Mr. Atkins

TABLE VII.
TENSILE STRENGTH OF PARK, BROTHER & CO. HOMOGENEOUS (CRUCH BOILER PLATE, 70,000 POUNDS.

SAMPLK.		BREAK- ING WEIGHT.	TENSILE STRENGTH PER SQUARE INCH.	ELONGA- TION IN PARTS OF AN INCH.	TIME CONSUMED IN TEST, IN MINUTES AND SECONDS.	WEIGHT ON THE MACHINE AT WHICH ELONGA- TION COM- MENCED.	REMARK
THICK- NESS.	WIDTH.						
.27	.98	20,000	75,585	.25	5.00	14,500	Short spec: U. S. re- tion.
.27	.98	19,700	74,452	.25	5.00	15,000	
.27	.98	20,400	77,097	.25	5.00	15,000	
.27	.98	19,400	73,318	.25	5.00	15,000	
.23	1.00	17,200	74,782	.25	4.00	14,000	
.235	1.00	18,000	76,595	.25	4.00	14,500	
.23	1.00	16,400	71,304	.3125	4.00	14,000	
.225	1.00	16,800	70,222	.3125	3.30	13,500	

TABLE VIII.

TENSILE STRENGTH OF 70,000 POUND STEEL BOILER PLATE, MADE BY
HUSSEY, HOWE & CO., PITTSBURG, PA. TESTS
BY MR. ATKINSON.

SAMPLE.		BREAK- ING WEIGHT.	TENSILE STRENGTH PER SQUARE INCH.	ELONGA- TION IN PARTS OF AN INCH.	TIME CONSUMED IN TEST, IN MINUTES AND SECONDS.	WEIGHT ON THE MACHINE AT WHICH ELONGA- TION COM- MENCED.	REMARKS.
THICK- NESS.	WIDTH.						
.25	1.00	18,300	73,200	.25	4.00	16,500	Short specimen U. S. regula- tion.
.25	1.00	19,000	76,000	.1875	4.30	17,000	
.25	1.00	18,000	72,000	.25	3.30	17,000	
.25	1.00	18,500	74,000	.25	4.00	17,200	
.25	1.00	18,800	75,200	.25	4.00	17,400	
.25	1.00	17,800	71,200	.25	3.30	16,500	
.25	1.00	17,600	70,400	.1875	3.30	16,000	
.25	1.00	18,400	73,600	.1875	4.00	17,000	

Bessemer steel is made by first melting in a cupola a charge of about six tons of pig iron rich in silicon and low in phosphorus; this molten metal is conducted by a suitable trough and allowed to flow into a large vessel called a "converter"—the details of its construction being such that air may be blown up through a perforated tuyere box placed in its bottom, thus compelling these jets of air to pass up through the molten metal. The oxygen in these jets of air having a greater affinity for the silicon than for anything else in the converter combines with it first and causes the charge to "work hot," after which the carbon begins to burn, and, as described by Mr. Holley, "the volume and brilliancy of the flame increase and the surging mass grows hotter and boils over in splashes of fluid slag; the discharge is a thick, white, roaring, dazzling blaze, and the massive vessel and its iron foundations tremble

under the violent ebullition. Towards the close of the operation the flame becomes thinner, and when decarbonization is complete it suddenly contracts and loses illuminating power. The determination of this period is the critical point of the process. Ten seconds too much or too little blowing injures or spoils the product. At the proper instant, as determined best by the spectroscope or by colored glasses, but usually by the naked eye, the foreman turns down the vessel and shuts off the blast. The charge of melted spiegel-eisen is then run in, when another flaming reaction occurs. The vessel being still further depressed, the steel runs into the ladle, pure, white and shining, from under its coating of red hot slag. A blanket of slag, most useful in preserving its temperature, follows it into the ladle. The metal is now led into the ingot moulds. After the exterior surface of the steel has crystallized, the mould is removed and the ingot is ready for reheating and rolling."

The time occupied in the conversion is about twenty minutes or until the carbon is exhausted. As already stated, a pig iron is selected rich in silicon; from two to two and a half per cent being the usual quantity. The oxidation of the silicon and carbon is, to a certain extent, done at the expense of the quality of the iron in the converter, which takes up more or less oxygen; the effect of this oxide of iron is to render the whole mass red-short, a property which may be corrected by the addition of manganese. This is supplied in the melted spiegel-eisen run into the converter after the "blow." The quantity admitted depends upon the required quality of the product. If the steel is to be low in carbon, less spiegel-eisen is introduced than if a higher steel is wanted. In practice, from eight to ten per cent is added.

The manganese also improves the product by neutralizing the deleterious effect of any sulphur that may be present, and by preventing ebullition of the metal when poured into the ingot moulds.

The following is an average analysis of the pig iron used at the works of the Cambria Iron Company in making Bessemer steel and well represents, in average composition, what is generally known in the market as Bessemer pig:

Silicon	2.50	per cent.
Carbon.....	4.00	per cent.
Sulphur.....	0.022	per cent.
Phosphorus	0.08	to 0.10 per cent.
	<hr/>	
	6.602	
[Iron by difference.....	93.398]	
	<hr/>	
	100.000	

The phosphorus may be reduced to 0.07 per cent when required for special steel.

The spiegel-eisen made by this company consists in average composition of

Manganese.....	15.0
Carbon	4.3
Silicon	0.3
Phosphorus.....	0.08

The quantity of manganese may be varied from six to thirty per cent, according to the special use for which it is required.

Analysis of the two samples of American spiegel-eisen made at Newark, New Jersey, by the New Jersey Zinc Company:

TABLE IX.

SAMPLES.	A	B
Iron	83 250	83.22
Manganese.	11.586	11.67
Phosphorus.	0.196	0.19
Silicon.	0.367	0.99
Carbon.	4.632	4.03
	100.031	100.10

As no phosphorus is removed from the iron by the Bessemer process, it is important to select a pig iron containing less of this impurity than may be safely allowed in the steel.

Manganese has the effect to neutralize the hardening action of phosphorus as well as to neutralize the red-short tendency due to the oxide of iron in the converter and when it does not exceed one per cent it has a toughening effect on the whole mass of metal.

Bessemer boiler plates should be low in carbon, silicon and phosphorus, and may contain 0.5 to 0.8 per cent of manganese.

Bessemer steel is now largely employed in England in the construction of steam boilers. Whatever doubts may have been expressed as to its reliability in years past, there seems now to be no doubt of its entire suitability for boiler plates. When the Bessemer process was new, workmen had to be educated to a new business and there was then much less of strictly scientific control in the management than at present. The material itself, the process of manufacture, the special machinery required, were all new and it would be contrary to human experience if the product was not variable in quality.

The Bessemer process is now well understood and there is no lack of specially trained workmen under the direction of men who have had a scientific training. The result is, the production of a low priced steel of any desired character, practically uniform in quality, which can be furnished with scarcely any limitations as to quantity. The one thing lacking heretofore in this steel has been uniformity. Manufacturers, by a careful selection and manipulation of materials, have practically solved that problem so that uniformity may be said to be under as thorough control in this as in any other process.

The chemistry of steel making is wholly in the hands of the manufacturer. How much carbon, manganese, etc., it shall contain is seldom or never fixed by the customer, who, except in very rare instances, must work whatever material the maker of the steel thinks is best suited to any particular use, the recourse of the purchaser being in the rejection of plates which do not come up to certain prescribed mechanical tests. These are usually the ordinary temper and bending tests; and then for tensile strength, elongation and reduction of area under pulling stress. If the steel will stand these latter tests, the purchaser cares little about its chemical composition.

The boiler maker, in addition to the mechanical tests given above, insists upon having a material which may be subjected to the various operations of bending, forging, local heating, flanging, annealing, punching, drilling and riveting, without impairing its character and strength. The question whether Bessemer plates should be punched or drilled is still an open one and opinions are pretty nearly evenly divided. This is a question of considerable commercial importance, for if these plates are to be drilled in order to be safe, it practically confines their use to large and well equipped establishments.

The practice, at Crewe, England, where are located the extensive works of the London & North-Western Railway Company, is to use steel exclusively for the shells of boilers. Mr. Webb's practice is to punch all rivet holes and then thoroughly anneal the plates before riveting. It was found that the plates over three-eighths inch lost strength by punching to the extent of about one-third and that the whole of this one-third was restored by annealing. As this company uses Bessemer plates in about four hundred locomotive boilers now in actual service, this circumstance alone carries great weight as an indorsement of this material in boiler construction.

Bessemer steel plates have been used almost solely by this company for over twelve years, and it is said, with entire satisfaction. The anomaly of this railway company using nothing but steel plates is of easy explanation. The company is not only singular in manufacturing the material for its permanent way and rolling stock, but it is equally fortunate in having a locomotive superintendent and works manager who is quite as much at home in manufacturing steel as in building locomotives, and it may be safely affirmed that no one else has had as much experience in the making and using of Bessemer steel plates.* The power and facility here afforded of choosing the most suitable standard of material for rails, axles, tyres and boiler plates from the different casts, may possibly account for the bold and successful lead so long held by the London & North-Western Railway Company in adopting the material that others may admire, but hold back from using.

It is a practice with this company to make an analysis of each cast in the steel melting department. Every plate used in the boiler shop has a piece sheared off and subjected to certain standard bending and drifting tests, the

* Engineering.

latter consisting in drifting out cold, to two inches in diameter, a five-eighth inch hole in a strip two and a half inches wide. These plates have a tensile strength of about seventy-five thousand pounds per square inch and suffer an elongation of twenty-five per cent before breaking.

The following analysis and mechanical tests of English *Bessemer mild steel* are by Mr. Daniel Adamson, Manchester, England :

ANALYSIS.

Iron.....	99.300
Carbon.....	.130
Manganese.....	.468
Silicon.....	.023
Sulphur.....	.031
Phosphorus.....	.037
Not accounted for.....	.011

100.000

MECHANICAL TESTS.

Length of specimen.....	10 inches.
Breadth of specimen.....	2.66 inches.
Thickness of specimen.....	.375 inches.
Area of specimen.....	1 square inch.
Permanent set induced per square inch...	44,500 pounds.
Maximum strain per square inch.....	67,000 pounds.
Elongation where maximum strain is applied.....	15 per cent.
Final breaking strain on original area per square inch.....	58,000 pounds.
Elongation	26 per cent.

Bessemer steel has not been used to any considerable extent in this country in the manufacture of steam boilers. The writer saw at the Edgar Thompson steel works, Bessemer, Pa., several large boilers made of Bessemer steel of their own manufacture.

Samples of this steel were subjected to both tensile and torsional tests, resulting as below :

(5)

TABLE X.

SHOWING TESTS OF BESSEMER STEEL BLOOMS FOR BOILER PLATE, MANUFACTURED BY THE EDGAR THOMPSON STEEL WORKS. SAMPLES FIVE-EIGHTHS INCH IN DIAMETER AND ONE INCH LONG BETWEEN SHOULDERS, TESTS MADE IN THEIR LABORATORY AND USING THE AUTOGRAPHIC RECORDING TESTING MACHINE DESIGNED BY PROF. R. H. THURSTON.

	SAMPLES.		
	A	B	C
Angle of torsion.....	282°	239°	217°
Moment of torsion, foot-lbs.....	312.15	295.74	288.46
Tensile strength at elastic limit.....	47,211	39,751	43,477
Ultimate tensile strength.....	64,271	65,120	65,664
Per cent of elongation.....	83.4	64.3	65.1
Carbon.....	0.10	0.16	0.15

The following test was made similar to the above, and from the same grade of metal, in which the

Angle of torsion was.....	254°
Moment of torsion.....	313.39 foot-lbs.
Tensile strength at elastic limit.....	39,751
Ultimate tensile strength.....	67,295
Per cent of elongation.....	70.8

This same sample showed by chemical analysis,

Carbon	0.12
Silicon.....	0.005
Phosphorus.....	0.078
Manganese.....	0.761
	0.964
[Iron, by difference.....	99.036]
	100.000

Three other analyses of boiler plate gave results as follows:

TABLE XI.

	(1)	(2)	(3)
Carbon	0.15	0.10	0.09
Silicon	0.018	0.14	0.028
Phosphorus.....	0.060	0.69	0.60
Manganese	0.784	0.755	0.541
Sulphur.....	Not det.	Not det.	0.0394

Two test pieces were sheared off the plates rolled for the boilers above referred to and sent to Mr. H. W. Borntraeger, superintendent of the Union Iron Mills, Pittsburg, Pa., who tested them on a Riehle Brothers' testing machine, with results as below :

TABLE XII.

MECHANICAL TESTS OF BESSEMER BOILER PLATE, MANUFACTURED BY THE EDGAR THOMPSON STEEL WORKS. TEST BY MR. BORNTRAEGER.

SAMPLES.	A	B
Length of sample.....	3 inches.	3 inches.
Thickness of sample.....	.29 inch.	.29 inch.
Width of sample.....	.63 inch.	.63 inch.
Area of sample.....	.1827 inch.	.1827 inch.
Elastic limit of sample.....	9,000 pounds.	9,000 pounds.
Elastic limit per square inch.....	49,250 pounds.	49,250 pounds.
Weight at which sample broke.....	12,350 pounds.	12,100 pounds.
Tensile strength per square inch.....	67,590 pounds.	66,225 pounds.
Elongation.....	$\frac{7}{16}$ inch, $2\frac{1}{2}$ inches.	$\frac{9}{16}$ inch, 3 inches.
Elongation, per cent.....	17 $\frac{1}{2}$	18 $\frac{1}{4}$

TABLE XIII.
MECHANICAL TESTS OF BESSEMER BOILER PLATE, MANUFACTURED BY
THE EDGAR THOMPSON STEEL WORKS. TEST BY
MR. BORNTRAEGER.

SAMPLES.	A	B
Length of sample.....	3 inches.	3 inches.
Thickness of sample.....	.36 inch.	.40 inch.
Width of sample.....	.62 inch.	.65 inch.
Area of sample.....	.2232 inch.	.2600 inch.
Elastic limit of sample.....	8,400 pounds.	9,400 pounds.
Elastic limit per square inch.....	37,600 pounds.	36,153 pounds.
Weight at which sample broke.....	13,100 pounds.	14,450 pounds.
Tensile strength per square inch.....	58,690 pounds.	55,590 pounds.
Elongation.....	$\frac{1}{8}$ inch, 3 inches.	$\frac{3}{8}$ inch, 3 inches.
Elongation per cent.....	31 $\frac{1}{4}$	25 $\frac{5}{16}$

Open hearth steel—This is also known as Siemens-Martin steel. The furnace or hearth in this process has usually a capacity of about eight tons. In the manufacture of boiler plate the charge consists of a charcoal pig iron selected with reference to its purity and freedom from silicon, sulphur, phosphorus, etc., care being taken that the total carbon is not of too high percentage, a No. 3 foundry pig being about the right grade. This pig constitutes about twenty-five per cent of the entire charge; it is melted in the hearth and brought to a very high heat, when charcoal blooms or other wrought iron of similar grade previously heated to a bright red heat are then immersed in the bath and allowed to dissolve in it. These charges are usually from six to eight hundred pounds and are introduced continuously every twenty or thirty minutes, until the carbon in the whole mixture is brought to the desired point, which for boiler plate is from 0.10 to

0.20 per cent, and the silicon is reduced either by fusion or by chemical action to the minimum amount, say from 0.01 to 0.05 per cent. Tests are now made to determine the quality of the metal in the bath. This is done by taking out a small test ingot, which, after cooling in water, is broken and tested. The fracture gives very good indications of the state of the charge. If in the judgment of the melter the metal is sufficiently refined, high grade ferro-manganese previously heated is now put into the bath and the whole mass of metal thoroughly stirred and then run out into a large ladle, from which it is poured into the ingot moulds. These ingots are then rolled into plates in the ordinary manner.

The process just described is, in its salient points, the ordinary routine of steel making. This process allows considerable latitude in manipulation, so that it is to be expected that different manufacturers, widely separated, would pursue different methods of working.

Carbon—The total quantity of carbon in steel plate made by the open hearth process may be varied to suit circumstances, as tests may easily be made before drawing the charge. Steel boiler plate having carbon in proportions varying from 0.10 to 0.20 per cent have given good results in practice. The latter figure is rather high to secure the greatest ductility and ought not to be exceeded. An excess of carbon increases the tensile strength of steel at the expense of its ductility and elasticity—hence, makers aim to produce a steel for boilers having a tensile strength of about sixty-five thousand pounds per square inch, and the analyses of samples so tested are found to contain from 0.10 to 0.15 per cent of carbon; 0.13 is found to give excellent results in practice.

Manganese—The exact function of manganese in steel is not clearly understood; the belief is, however, that

it deoxidizes the bath, as well as removes the sulphur. This is inferred from the disappearance of most of the sulphur from the iron in the bath and partly from the circumstance that only about one-half of the metallic manganese, added at the last of the charge, is found in the analysis of the resultant steel. An excess of manganese in steel boiler plate has the effect to reduce its ductility and elasticity, 0.25 per cent is ample for hot working, and good results have been obtained from steel plates having manganese present in the proportion of 1.50 of manganese to 1.00 of carbon.

The relative proportions of carbon and manganese in open hearth boiler plate is confined within comparatively narrow limits to get the best results. An excellent quality of plate made at different times by the same furnace was found to contain, upon analysis, the following quantities of each :

TABLE XIV.

	CARBON.	MANGANESE.	RATIO OF CARBON TO MANGANESE.
A	.10 per cent.	.17 per cent.	1 to 1.7
B	.11 per cent.	.18 per cent.	1 to 1.64
C	.11 per cent.	.22 per cent.	1 to 2.
D	.11 per cent.	.24 per cent.	1 to 2.18
E	.12 per cent.	.16 per cent.	1 to 1.33
F	.12 per cent.	.17 per cent.	1 to 1.41
G	.12 per cent.	.25 per cent.	1 to 2.08
H	.13 per cent.	.17 per cent.	1 to 1.30
I	.13 per cent.	.20 per cent.	1 to 1.54
J	.13 per cent.	.23 per cent.	1 to 1.77

The manufacture of steel plates by the open hearth process in the United States dates from 1871 and attained

a high degree of perfection in a short time afterward, as shown by the following mechanical tests made by the United States government to determine its suitability for ship building. The tests were made in 1873 by Mr. Samuel H. Pook, naval constructor, and F. L. Fernald, assistant naval constructor, United States Navy. The steel tested was made by the Nashua Iron and Steel Company:

The first test was made with reference to the tensile strength, and for that purpose two pieces were selected from plates having a thickness of nine-sixteenths, ten-sixteenths and eleven-sixteenths, respectively. These six pieces gave a mean tensile strain of 27.82 tons (62,316.8 pounds) per square inch of original section; 65.30 tons (146,272 pounds) per square inch of fractional section, an elongation of two and one-sixteenth inches in a length of eight inches, and a mean strain of 19.06 tons (42,694.4 pounds) per square inch without stretch, or sixty-five per cent of breaking strain. The strain was the same in all samples and the strength was remarkably uniform.

The cold forge tests were made with plates nine-sixteenths and five-eighths inches in thickness. It was found that the samples could be folded over until the surfaces met, without any perceptible evidences of fracture. A nine-sixteenths inch plate was placed over a hole nine by nine inches square in a piece of wrought iron, a six-inch cast iron shot was then driven down by a two thousand pound steam hammer having a mean stroke of twenty-four inches, until the calotte or cup thus formed had a depth of four and three-eighths inches. The lower surface was then thoroughly examined and no signs of fracture could be detected. A second trial was then similarly made upon a plate eleven-sixteenths inch thick, with a view to ascertain to what extent this test could be carried without fracture.

After breaking three shot, a wrought iron cylinder with a spherical end was substituted, and at about the sixtieth blow disintegration took place along one side of the cup at a distance of two inches from its bottom. The thickness of the plate at the point of fracture was reduced to one-quarter inch, the depth of the cup being four and seven-eighths inches.

When heated it was found that the plate could be folded over until the surfaces met, and then bent in the opposite direction to a similar position without fracture, and after repeating this operation four times only a slight fracture took place.

Hot tests were made also in the following manner:

A three-quarter-inch hole was punched in a cold plate; the plate was then several times heated and the hole pinned out until a cylinder was formed five inches in diameter and five inches long. After it was thoroughly cold a flange was turned down all around the end, the surface remaining perfectly free from cracks and other defects.

Right angled, inside and outside corner flanges were formed with the greatest ease; no amount of heating appeared to affect the malleability in the least. With a view to ascertain if the scrap which would be made in building a ship could be utilized, about sixty pounds of samples were made up into three-quarters of an inch round bars in precisely the same manner as ordinary iron.

The tensile strength of this bar was found to be 29.62 tons (66,349 pounds) per square inch, or one and one-eighth ton (twenty-five thousand two hundred pounds) more than from the original plate. Several rivets were made from the bar which stood a double shearing strain of 21.55 tons (48,272 pounds) or 48.76 tons (109,222 pounds) per square inch.



An analysis of this steel was made by Mr. J. A. Herrick in 1873. The ingot steel tested before reheating and rolling showed 0.14 per cent of carbon. The following is that of the finished plate :

Carbon (combined)	0.130	$\left\{ \begin{array}{l} 0.1320 \text{ } \end{array} \right\}$ per cent by the chloride of copper $\left\{ \begin{array}{l} 0.1297 \text{ } \end{array} \right\}$ method. 0.1100 by combustion in chlorine and then in oxygen.
Carbon (graphite).....	none	
Manganese.....	0.100	
Sulphur.....	0.028	
Phosphorus	0.011	
Silica.....	0.071	by the chlorine combustion method.
Iron (difference).....	99.660	
Total.....	100.000	

The pig iron used was the Workington hematite cold last charcoal, from the Cumberland district, England, and obtained by Mr. Herrick's analysis :

Silicon.....	0.360	by the chlorine combustion method.
Slag.....	2.800	by the chlorine combustion method.
Carbon (combined).....	0.552	by the chloride of copper method.
Carbon (graphite).....	3.178	by the chloride of copper method.
Sulphur	0.052	
Phosphorus	0.016	
Manganese	0.080	
Iron (difference).....	92.962	
Total.....	100.000	

The charcoal blooms used in this mixture were made from Rodger's bed ore, Chateaugay lake, Clinton county, New York, and by Mr. Herrick's analysis contained :

Silica.....	0.418	by the chlorine combustion method.
Slag.....	0.030	by the chlorine combustion method.
Sulphur.....	0.038	
Phosphorus	0.005	
Manganese.....	trace	
Carbon.....	0.250	by the chloride of copper method.
Iron (difference).....	99.259	
Total.....	100.000	

The steel just described was made of a quality suitable for ship building, and for steam boilers; the elements

being in all essentials the same for the two kinds of service. It shows remarkable toughness, combined with a reasonable tensile strength.

The following tests by Mr. Richards were made on the same kind of steel, but manufactured in another section of the country:

TABLE XV.

SHOWING THE EFFECTS OF TENSILE STRAINS ON SEVERAL SAMPLES OF STEEL PLATES RECEIVED JANUARY 15, 1875, FROM THE OTIS IRON AND STEEL COMPANY, OF CLEVELAND, OHIO, AND TESTED FOR THEM BY C. B. RICHARDS, ENGINEER, HARTFORD, CONN.

Long Specimens.

TEST NUMBER.	MANUFACTURER'S MARK.	ORIGINAL MINIMUM CROSS SECTION.		AREA OF LEAST SECTION AFTER FRACTURE.	LENGTHS.		LEAST STRAIN, WHICH PRODUCED A PERMANENT SET.	BREAKING STRAIN.	ELASTIC LIMIT PER SQUARE INCH.	TENSILE STRENGTH PER SQUARE INCH OF ORIGINAL MINIMUM CROSS SECTION.	REDUCTION OF CROSS SECTION BY BREAKING.	ULTIMATE ELONGATION.
		DIMENSIONS.	AREA.		ORIGINAL LENGTH OF MINIMUM SECTION, MEASURED BETWEEN THE SHOULDERS.	LENGTH AFTER FRACTURE.						
		INCH.	SQ. IN.	SQ. IN.	INCHES	IN'S	LBS.	LBS.	LBS.	LBS.	P. CT.	P. CT.
506	28.28. X	1.00x0.375	0.375	0.133	10.0	11.55	10,000	21,120	27,000	56,320	65.0	15.5
507	28.28. X	1.00x0.375	0.375	0.131	10.0	11.50	12,000	20,900	32,000	55,733	65.0	15.0
508	28	1.00x0.350	0.350	0.144	10.0	11.48	9,000	20,140	26,000	57,543	59.0	14.8
509	28H	1.00x0.350	0.350	0.200	10.0	10.70	10,000	27,680	29,000	79,086	43.0	7.0
510	12	1.00x0.300	0.300	0.105	10.0	11.68	10,000	16,900	33,000	56,333	65.0	16.8
512	32	1.00x0.312	0.312	0.117	8.0	9.58	12,000	17,900	38,000	57,371	62.5	19.8
514	7	1.00x0.323	0.323	0.117	8.0	9.73	13,000	18,230	40,000	56,440	63.0	21.6
516	38	1.00x0.325	0.325	0.148	8.0	9.49	9,000	.....	28,000	.....	54.5	18.6
518	38	1.00x0.325	0.325	0.159	8.0	9.31	12,000	22,715	38,000	62,470	51.0	16.2

TABLE XV—CONTINUED.

Short Specimens.

TEST NUMBER.	MANUFACTURER'S MARK.	ORIGINAL MINIMUM CROSS SECTION.		AREA OF LEAST SECTION AFTER FRACTURE.	LENGTHS.		LEAST STRAIN, WHICH PRODUCED A PERMANENT SET.	BREAKING STRAIN.	ELASTIC LIMIT PER SQUARE INCH.	TENSILE STRENGTH PER SQUARE INCH OF ORIGINAL MINIMUM CROSS SECTION.	REDUCTION OF CROSS SECTION BY BREAKING.	ULTIMATE ELONGATION.
		DIMENSIONS.	AREA.		ORIGINAL LENGTH OF MINIMUM SECTION, MEASURED BETWEEN THE SHOULDERS.	LENGTH AFTER FRACTURE.						
		INCH.	SQ. IN.	SQ. IN.	INCHES	IN'S.	LBS.	LBS.	LBS.	LBS.	P. CT.	P. CT.
541	12	1.00x0.310	0.310	0.151	0	.....	.....	19,800	.....	63,871	52.0	.....
543	32	1.00x0.311	0.311	0.132	0	.....	.....	20,330	.....	65,370	58.0	.....
545	7	1.00x0.323	0.323	0.154	0	.....	.....	21,660	.....	66,935	52.4	.....
547	38	1.00x0.325	0.325	0.159	0	.....	.....	22,715	.....	69,277	51.0	.....

The numbers obtained by dividing the breaking strain by the area of least section after fracture, sometimes called "the tensile strength per square inch of fractured area," give a valuable measure of the toughness of the material. These numbers are as follows, for the several specimens:

No. 506.....159000.	No. 512.....153000.
No. 507.....160000.	No. 513.....155000.
No. 508.....140000.	No. 514.....155000.
No. 509.....138000.	No. 515.....140000.
No. 510.....161000.	No. 517.....143000.
No. 511.....131000.	No. 518.....166000.

The strains were applied gradually in all cases.

With specimen No. 516, the breaking strain was not observed; but No. 518, of the same material, was afterward broken and the result recorded.

REMARKS BY OTIS IRON AND STEEL COMPANY.

The above samples contained the following percentages of combined carbon: No. 28, .0014 per cent; No. 12, .0013½ per cent; No. 32, .0014 per cent; No. 7, .0012 per cent; No. 38, .0014 per cent.

Samples marked ^{28, 32, 38}_x were taken from across the sheet.

Sample marked 28 H was heated red hot and cooled in water before being broken, and although the strength is increased, there is no perceptible increase in the hardness when tried with the file.

Samples No. 28, No. 12, No. 32, No. 7, were uniform in mixture and quality of stock used.

Several very severe mechanical tests, to show the qualities of open hearth homogeneous boiler plate, were made with cold plates at the works of this company at Cleveland, Ohio, in the presence of the writer, to whom the samples were also given. The pieces tested were sheared off the ends of plates, which were then being cut to dimensions in their ordinary business routine.

Several unannealed samples from plates five-sixteenths of an inch thick were folded down in the usual manner by blows given by a heavy hammer. Samples were also subjected to a shearing test, in which a piece of steel three inches in width was sheared up to within an eighth of an inch of the edge without exhibiting any signs of fracture, the "shearing" being depressed more than half an inch on the opposite edge of the plate. A number of these "shearings" were made at a distance of about five-eighths of an inch apart. A sample about eight inches square, taken off another plate selected at random on the floor of the mill, was folded over flat and afterward folded again at right angles to the first, the whole being then hammered flat, making a specimen about four inches square and one and a quarter inches thick, without exhibiting any signs of fracture.

A selection of five tests was taken from their laboratory record to show the range in tensile strength allowable in this system of manufacture. The tests were made with the ordinary two-inch specimens, with results as follows:

TABLE XVI.

SHOWING THE RANGE IN TENSILE STRENGTH OF OPEN HEARTH STEEL PLATES MADE BY THE OTIS IRON AND STEEL COMPANY.

TEST NO.	DESCRIPTION.	DIMENSIONS.	AREA.	ORIGINAL LENGTH OF MINIMUM SECTION MEASURED BETWEEN SHOULDERS.	BREAKING STRAIN.	TENSILE STRENGTH PER SQ. INCH OF ORIGINAL MINIMUM CROSS SECTION.	ULTIMATE ELONGATION.
	PLATE.			INCHES.	POUNDS.	POUNDS.	PER CT.
877	$\frac{5}{16}$	.98x.374	.366	2.	16,300	44,530	49
1501	$\frac{5}{16}$	.986x.319	.315	2.	18,200	57,770	44
1879	$\frac{3}{8}$	.913x.37	.339	2.	21,300	62,830	34
1521	$\frac{1}{2}$	.64x.519	.332	2.	23,750	71,530	33
1905	$\frac{3}{4}$	.851x.25	.213	2.	17,975	84,390	25

The first line in the above table shows the remarkably low tensile strength of forty-four thousand five hundred and thirty pounds per square inch. It is seldom that steel is made so low as that; and is less than is to be recommended for boilers, as such plates are apt to be spongy. The last line in the table showing eighty-four thousand three hundred and ninety pounds tensile strength, is less ductile, as will be observed by comparing the percentages of elongation—the ratio being twenty-five to forty-nine per cent. This latter grade of metal is too high for boilers; suffering more in punching, lacking in ductility and is more likely to be brittle than steel ranging from sixty thousand to seventy thousand pounds.

TABLE XVII.

TENSILE STRENGTH OF 60,000 POUNDS OPEN HEARTH STEEL, MADE BY
SINGER, NIMICK & CO., PITTSBURG, PA. TESTS
BY MR. ATKINSON.

SAMPLE.		BREAK- ING WEIGHT.	TENSILE STRENGTH PER SQUARE INCH.	ELONGA- TION IN PARTS OF AN INCH.	TIME CONSUMED IN TEST, IN MINUTES AND SECONDS.	WEIGHT ON THE MACHINE AT WHICH ELONGA- TION COM- MENCED.	REMARKS.
THICK- NESS.	WIDTH.						
.25	.98	15,000	61,224	.3125	MIN. SEC. 3.30	12,000	Short specimen U. S. regula- tion.
.25	.98	15,400	62,857	.25	3.30	12,500	
.25	.98	16,400	66,938	.25	4.00	13,500	
.25	.98	15,000	61,224	.25	3.00	12,000	
.25	.98	16,000	65,306	.25	4.00	12,500	
.25	.98	15,300	62,449	.25	3.30	12,000	
.25	.98	15,500	63,265	.25	4.00	12,000	
.25	.98	15,700	64,081	.25	4.00	12,500	

This table and the one following is, so far as tensile strength is concerned, the grade of steel recommended for boiler making, and if the steel is properly made it ought to be able to withstand all the mechanical tests ordinarily demanded in construction. Test pieces in tables XVI, XVII and XVIII were as shown in figure 2.

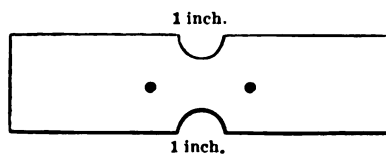


FIGURE 2.

TABLE XVIII.

STRENGTH OF 65,000 POUNDS OPEN HEARTH STEEL MADE BY
SINGER, NIMICK & CO., PITTSBURG, PA. TESTS BY
MR. ATKINSON.

WIDTH.	BREAKING WEIGHT.	TENSILE STRENGTH PER SQUARE INCH.	ELONGATION IN PARTS OF AN INCH.	TIME CONSUMED IN TEST IN MIN. AND SEC.	WEIGHT ON MACHINE AT WHICH ELONGATION COMMENCED.	REMARKS.
				MIN. SEC.		
00	17,500	70,000	.25	4.00	13,500	Short speci- men U. S. regulation.
00	16,800	67,200	.25	3.30	13,500	
00	17,300	69,200	.25	4.00	14,000	
00	15,700	68,260	.25	3.00	13,000	
00	15,800	67,234	.25	3.30	13,000	
98	14,800	65,661	.25	3.00	13,000	
00	15,400	65,531	.25	3.30	13,000	
00	15,900	67,659	.25	3.30	13,000	
00	15,200	66,086	.25	3.00	13,000	
00	15,300	66,522	.25	3.00	13,000	
00	15,400	65,531	.25	3.00	13,000	
00	15,000	65,217	.25	3.00	13,000	
00	16,200	68,936	.25	3.00	13,000	

next table (XIX) gives the tensile strength of ten of seventy thousand pound steel. This tensile ought not to be exceeded in boiler plates, as plates of strength are more liable to fracture, are less ductile, more likely to harden than the lower grades.

TABLE XIX.
TENSILE STRENGTH OF 70,000 POUNDS OPEN HEARTH STEEL, MADE BY
SINGER, NIMICK & CO., PITTSBURG, PA. TESTS BY
MR. ATKINSON.

SAMPLE.		BREAKING WEIGHT.	TENSILE STRENGTH PER SQUARE INCH.	ELONGATION IN PARTS OF AN INCH.	TIME CONSUMED IN TEST IN MIN. AND SEC.	WEIGHT ON MACHINE AT WHICH ELONGATION COMMENCED.	REMARKS.
THICKNESS.	WIDTH.						
.23	.99	16,400	72,400	.3125	MIN. SEC. 5.00	11,500	Short spec- men U. S regulation
.23	.99	16,100	70,707	.25	5.00	11,500	
.23	.99	16,500	72,463	.25	5.00	12,500	
.225	.99	15,700	70,482	.3125	4.30	11,500	
.225	.98	15,500	70,294	.3125	4.00	12,000	
.23	.99	16,400	72,024	.25	5.00	12,500	
.23	1.00	17,400	75,652	.25	5.30	12,500	
.23	1.00	17,300	75,217	.25	4.30	12,000	
.225	.99	15,700	70,482	.25	4.00	11,500	
.225	.99	15,800	70,931	.25	4.00	11,500	

The following is taken from a valuable and interesting paper on “The properties of iron and steel,” by Daniel Adamson, C.E., Manchester, England.

SIEMENS-MARTIN STEEL.

ANALYSIS.	
Iron	99.224
Carbon .....	.200
Manganese.....	.500
Silicon.....	.009
Sulphur .....	.035
Phosphorus.....	.032
<hr/>	
100.000	

MECHANICAL TESTS.

Length of specimen.....	10	inches.
Breadth of specimen.....	2.06	inches.
Thickness of specimen .....	.485	inch.
Area of specimen	1.0	square inch.
Permanent set induced per square inch.....	34,500	pounds.
Maximum strain per square inch.....	59,500	pounds.
Elongation when maximum strain is applied.....	16.5	per cent.
Final breaking strain on original area per square inch	50,500	pounds.
Elongation.....	27	per cent.

(6)



CHAPTER V.

TESTING WROUGHT IRON OR STEEL FOR BOILERS.

Bending Tests—Temper Test—Drifting Test—Tensile Strength—Size and Shape of Samples for Testing—Long and Short Specimens—French, English and American Practice—Elongation—Reduction of Area—Elastic Limit—Percussion Tests—Bulging Tests—English Admiralty Tensile and Forge Tests for Boiler Plate—Mr. Kirkaldy on Testing Iron.

Testing wrought iron or steel for boilers—The tests to which these materials of construction are subjected are both cold and hot.

Bending test—The simplest and at the same time a most satisfactory test is to shear off a strip of any convenient width, say, one to two inches, and bend it down cold with a sledge hammer until the plates touch, as shown in figure:



FIGURE 3.

Very few irons, except the better grades of flange iron, will stand a test of this kind. In the manufacture of steel plates this is the ordinary mill test, and it is the practice of all reputable manufacturers to reject any plate five-sixteenths of an inch thick and less which will not stand this test without breaking.

The temper test (for steel) consists in shearing a similar strip from a plate and heating it to a low cherry red heat

ddenly quenching in water, allowing it to remain until cold and then bending the sample over double the diameter of the inner curve is from two to three the thickness of the plate, without exhibiting any fracture. The former bending test is not so effective, for the reason that it might not detect a hard hat had been well annealed before shearing, but by bending the strip the hard and comparatively brittle of the plate immediately discloses itself.

drifting test consists in shearing samples two and half inches wide and punching a five-eighth inch hole in center, annealing thoroughly and "drifting" the plate with taper pins. The larger the hole the better the material; it is expected that ordinary steel plates will drift to twice the diameter of the punch without showing signs of fracture. Mr. Webb's standard, at Crewe, is to drift the $\frac{5}{8}$ -hole out to two inches in diameter in Bessemer plates entering into locomotive boilers.

Tensile strength—The tests for tensile strength consists in drawing a specimen similar to figure 4, having an area of one square inch at its narrowest cross section. This specimen is adjusted in a testing machine and

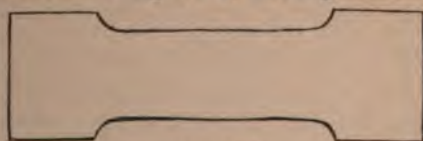


FIGURE 4.

is loaded until it breaks. This breaking weight, multiplied by the original fractional area of the specimen, is the tensile strength per square inch of the material.

The lowest grade of wrought iron, entering into the construction of the shells of steam boilers, should stand a tensile strain of at least 45,000 pounds per square inch. The best irons range from 60,000 to 75,000 pounds and are usually higher.

For steel boiler plates the tensile strength is to be kept as low as possible and insure sound and homogeneous ingots or plates. In crucible steel it is difficult to get it below sixty thousand pounds and should not exceed seventy-five thousand. In Bessemer and Siemens-Martin steels it may vary from fifty-five thousand to seventy thousand pounds.

TABLE XX.

STRENGTH OF AMERICAN IRON BOILER PLATE. TESTS MADE AT THE U. S. TREASURY DEPARTMENT, WASHINGTON.

NO.	THICKNESS IN INCHES.	TENSILE STRAIN IN POUNDS PER SQUARE INCH.	REDUCED AREA PER CENT.	HOW TESTED.
128	$\frac{1}{4}$	61,538	36	With the grain.
129	$\frac{1}{4}$	59,125	18	Across the grain.
136	$\frac{1}{4}$	58,373	38	With the grain.
135	$\frac{1}{4}$	53,333	9	Across the grain.
126	$\frac{3}{16}$	62,871	38	With the grain.
127	$\frac{3}{16}$	58,765	20	Across the grain.
134	$\frac{5}{16}$	62,195	43	With the grain.
133	$\frac{5}{16}$	60,202	10	Across the grain.
124	$\frac{3}{8}$	61,481	30	With the grain.
125	$\frac{3}{8}$	58,653	22	Across the grain.
132	$\frac{3}{8}$	60,408	47	With the grain.
131	$\frac{3}{8}$	57,377	15	Across the grain.
148	$\frac{3}{8}$	56,270	25	With the grain.
149	$\frac{3}{8}$	54,461	17	Across the grain.
146	$\frac{1}{2}$	61,918	33	With the grain.
147	$\frac{1}{2}$	63,469	6	Across the grain.

Nos. 128, 129 were one-fourth inch iron reduced to the square of its thickness. Nos. 135, 136 were of the same iron and were nearly one inch wide. Nos. 126, 127 were of small, and 133, 134 were of larger area. Nos. 124, 125, 148, 149 were cut exactly the square of the thickness, and Nos. 131, 132 were of the same iron whose area approximated one-fourth of one square inch. Nos. 146 and 147 were samples of one-half inch, cut the square of its thickness.

It may be of interest to compare the relative tensile strengths of American with English boiler plates. The

figures in table XXI it will be observed, average considerably lower in the table immediately preceding. One thing in favor of the figures given of any tests made in England is, that test pieces are as a rule eight or ten inches long, while in this country they are usually the "short," though sometimes two inches long, and rarely six or eight inches, a difference which will be explained further along in this chapter.

TABLE XXI.

TENSILE STRENGTH AND DUCTILITY OF ENGLISH BOILER PLATE, AS DETERMINED BY MR. KIRKALDY'S EXPERIMENTS.

DISTRICT IN WHICH THE IRON IS MADE.	NAMES OF MAKERS OR WORKS AND BRANDS.	DIRECTION OF THE GRAIN AND THICKNESS IN INCHES.	TEARING WEIGHT PER SQ. INCH OF ORIGINAL SECTION IN LBS.	CONTRACTION OF AREA FRACTURED. PER CENT.	ULTIMATE ELONGATION OR TEN-SILE SET AFTER FRACTURE. PER CT.
Yorkshire.....	Lowmoor.....	L. $\frac{5}{16}$	51,990	19.7	13.2
Yorkshire.....	Lowmoor.....	C. $\frac{5}{16}$	50,512	12.1	9.3
Yorkshire.....	Farnley.....	L. $\frac{3}{8}$	56,000	17.8	14.1
Yorkshire.....	Farnley.....	C. $\frac{3}{8}$	46,211	13.2	7.6
Yorkshire.....	Bowling.....	L. $\frac{3}{8}$	52,237	15.3	11.6
Yorkshire.....	Bowling.....	C. $\frac{3}{8}$	46,435	6.9	5.9
Staffordshire.....	Bradley % Crown S. C.....	L. $\frac{1}{2}$	55,821	17.2	12.5
Staffordshire.....	Bradley % Crown S. C.....	C. $\frac{1}{2}$	50,445	9.0	5.5
Staffordshire.....	Thorneycroft, Best Best.....	L. $\frac{15}{16}$	54,835	12.5	11.2
Staffordshire.....	Thorneycroft, Best Best.....	C. $\frac{15}{16}$	45,584	4.6	4.6
Staffordshire.....	Lloyds, Foster, % Best.....	L. $\frac{3}{8}$ to $\frac{7}{8}$	44,957	8.7	5.3
Staffordshire.....	Lloyds, Foster, % Best.....	C. $\frac{3}{8}$ to $\frac{7}{8}$	44,621	6.9	4.6
North of England...	Consett, Best Best.....	L. $\frac{3}{4}$	51,251	13.1	8.9
North of England...	Consett, Best Best.....	C. $\frac{3}{4}$	46,704	10.2	6.4
Scotland.....	Glasgow, Best Best.....	L. $\frac{1}{4}$ to $\frac{3}{4}$	53,402	10.6	9.0
Scotland.....	Glasgow, Best Best.....	C. $\frac{1}{4}$ to $\frac{3}{4}$	41,776	3.7	2.6

L. signifies lengthwise, or in the direction of the grain.
C. signifies crosswise, or across the grain.

This subject has received a great deal of attention in England, and I quote from a paper by Mr. Marlett, chief examiner, Lloyd's Register, 1878, as follows:

"Another point of our investigations which has received our most anxious attention, is as to the limits within which the tensile strength should be confined.

"In the committee's circular, the limits are from twenty-six to thirty tons (58,240 to 67,200 lbs), and this agrees with the Admiralty requirements, but the weight of evidence we have been able to collect since the issue of that circular is in favor of somewhat higher limits. Mr. Sharp, of the Bolton Co., Mr. Webb, of Crewe, and Mr. Ellis, of Messrs. J. Brown & Co.'s works, urge that the upper limit might be raised to thirty-two tons (71,680 pounds) per square inch, without the slightest fear of obtaining brittle plates, so long as the temper and other tests are enforced. The Dutch government stipulate for a tensile strength of from twenty-seven to thirty-one tons (60,480 to 69,440 pounds) in their present contracts with the Bolton and Landore steel companies, and in contracts for boiler plates and other uses, the limits are fixed as high as thirty-three tons (73,920 pounds), although the steel has still to be mild and ductile. It is said by some that when steel gets down to about twenty-six tons (58,240 pounds) in tensile strength, it begins to be more spongy and is less capable of being welded than steel of twenty-eight tons (62,720 pounds) per square inch, and it is urged that steel between thirty and thirty-two tons (67,200 to 71,680 pounds) strength, if it fulfills all the other conditions of ductility, is a better material than the weaker, and sometimes less ductile, material having a tensile strength of twenty-six tons (58,240 pounds). Indications seem to show that these lower limits are more easily reached by the Siemens steel than by the Bessemer and an advantage is claimed for the latter at the higher limits. After giving the matter our most

careful consideration, we are of the opinion that it would on the whole be preferable to fix the limits at twenty-seven to thirty-one tons (60,480 to 69,440 pounds) per square inch, rather than twenty-six to thirty tons (58,249 to 67,200 pounds)."

The size and shape of samples for testing—It was but a few years since that the only experimental test to which boiler plate was subjected was to determine its tensile strength. It was then the custom to make test pieces short, or, rather, of no particular length, and with little or no uniformity of cross section, except at the point where rupture was to occur. The pieces were, however, usually of one of the outlines, as given in the accompanying sketches, in which figure 5 is designated as a long and figure 6 as a short specimen :

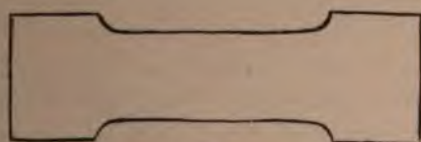


FIGURE 5.

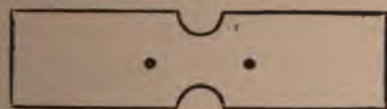


FIGURE 6.

In testing a plate to determine its tensile strength merely, this is perhaps well enough; but as nearly all tests are now required to show both tensile strength and ductility, it is recommended that test pieces be of the same length and sectional area, in order that results of different tests may be tabulated, and thus form an intelligent and ready means of comparison, preventing much needless con-

fusion, which must necessarily arise where specimens are of different lengths.

Experiments made to determine how the different lengths of specimens tested affects the percentage of elongation, show most clearly that if a fixed percentage of elongation is required, the specimen should be of fixed length. If, on the other hand, latitude is permitted in the length of the specimens to be tested, so as to suit the different testing machines, there should be a sliding scale for percentage of elongation. The different percentages of elongation for different lengths of specimens were found by experiment to be as follows:*

STRETCH OF HOMOGENEOUS STEEL PLATES.

Eight inch specimen.....	20 per cent.
Six inch specimen.....	25 per cent.
Four inch specimen.....	32 per cent.
Two inch specimen.....	37½ per cent.

The reason for these differences of percentages in elongation is obvious, and arises from the fact that near the point of fracture the elongation is much greater than at other parts of the specimen. With material, therefore, of equal quality, the shorter the specimen tested the higher will be the percentage of elongation; or, on the other hand, comparatively hard and brittle steel might easily be made to show a required twenty per cent of elongation by making the specimen sufficiently short for the purpose.

In testing samples of steel boiler plate it is of the utmost importance that the pull be exactly in the line of the sample, so that when fracture sets in, it shall be a break and not a tear. A material may be torn asunder at a pressure very much below that required to break it or pull it apart. Care should also be taken that no imperfections or "nicks" exist in the *test* portion of the sample.

* Committee Report, Lloyd's Register.

The eight inch specimen was first adopted by the French Admiralty and afterward by the English Admiralty, then by Lloyd's Register of English and Foreign Shipping, and thus a standard length forced itself upon the attention of manufacturers, so that it is now in very general use in Europe. It is much to be regretted that our own government still uses the short test specimens, particularly as little or no modifications would be required in the present testing machines in order to use the eight inch specimen. This would enable a direct comparison of American and foreign tests, which are always of great interest and value.

U. S. Government Tests—The instructions to local inspectors of steam boilers, so far as relates to the tensile strength of boiler plate, and contained in the rules and regulations prescribed by the Board of Supervising Inspectors of steam vessels, are as follows:

"RULE 3—Every iron or steel plate intended for the construction of boilers to be used on steam vessels shall be stamped by the manufacturer in the following manner, viz: At the diagonal corners, at a distance of about four inches from the edges, and also at or near the center of the plate, with the name of the manufacturer, the place where manufactured and the number of pounds tensile strain it will bear to the sectional square inch.

"When a sheet of boiler iron is found by the inspector with one or more stamps upon the same, the inspectors shall in every such case be governed and rate the tensile strain of iron in accordance with the lowest stamp found upon the same.

"RULE 4—The manner of inspecting and testing boiler plates, intended to be used in the construction of marine

boilers, by the United States inspectors, shall be as follows, viz:

“The inspector shall visit places where marine boilers are being constructed, as often as possible, for the purpose of ascertaining and making a record of the stamps upon the material, its thickness and other qualities. To ascertain the tensile strain of the plates, the inspector shall cause two pieces to be taken from each sheet to be tested, the area of one of which shall equal one-quarter of one square inch, the area of the other shall equal the square of its thickness, and the force at which these pieces can be parted in the direction of the fiber or grain, represented in pounds avoirdupois—the former multiplied by four, the latter in proportion to the ratio of its area—that piece showing the greater tensile strain shall be held to be the tensile strength of the plate from which the test pieces were taken, and should the tensile strength ascertained by the test equal that marked on the plates from which the test pieces were taken, the said plates must be allowed to be used in the construction of marine boilers; provided, always, that the said plates possess the other qualities required by law, viz, homogeneousness, toughness and ability to withstand the effect of repeated heating and cooling; but should these tests prove the marks on said plates to be overstamped, the lots from which the test plates were taken must be rejected as failing to have the strength stamped thereon. But nothing herein shall be so construed as to prevent the manufacturers from restamping such iron at the lowest tensile strain indicated by the samples, provided such restamping is done previous to the use of the plates in the manufacture of marine boilers.

“In the following table will be found the widths—expressed in hundredths of an inch—that will equal one-quarter of one square inch of section of the various thicknesses of boiler plates. The signs + (plus) and — (minus)

indicate that the numbers against which these signs are placed are a trifle more or less, but will not in any instance exceed one-thousandth of an inch.

"The gauge to be employed by inspectors and others to determine the thickness of boiler plates and the widths in the table will be the Darling, Brown & Sharp's gauge, of Providence, Rhode Island, and will be furnished by the Treasury Department. This gauge has been approved by the Board of Supervising Inspectors:

$\frac{5}{16}'' = 133 -$	$.26 = 96 -$	$.35 = 71 -$
$.21 = 119 -$	$.29 = 86 -$	$\frac{3}{8}'' = 67 +$
$.23 = 109 +$	$\frac{5}{16}'' = 80$	$\frac{7}{16}'' = 57 -$
$\frac{1}{4}'' = 100$	$.33 = 76 +$	$\frac{1}{2}'' = 50$

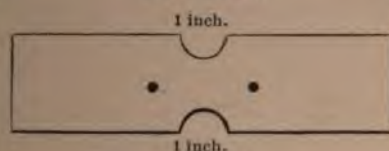


FIGURE 7.

"All samples intended to be tested on the Riehle testing machine must be prepared in form, according to the above diagram, viz, eight inches in length, two inches in width, cut out at their centers in the manner indicated. Two small center punch marks must be made on samples, one inch each side of their center, for the purpose of ascertaining their elongation or ductility.

"In commencing a test, the person conducting the same must first apply weights to within four thousand pounds of one-quarter of the tensile strength marked upon the sample, and, after pumping the machine to equilibrium, apply the remaining weights at intervals of about fifteen seconds, until the sample is parted.

"The smaller weights must be applied last, and should a sample part immediately on the application of such a weight, the weight last applied must be rejected.

"The machine must be kept at equilibrium during the application of the weights, and, after the first application is made, the point where elongation commences must be ascertained by applying a pair of dividers to the center punch marks, at every additional weight, until the test is completed.

"All tests made of boiler material must be recorded upon a table showing the following:

"Date when tests were made.

"From whom samples were obtained and by whom tested.

"Material, iron or steel.

"Stamp or label on samples, which must be the same as stamps on the material from which they are taken.

"Thickness of samples, expressed in hundredths of an inch.

"Width of samples, expressed in hundredths of an inch.

"Strain at which each sample parted.

"Strain per square inch of section.

"Elongation of samples, expressed in hundredths of an inch.

"Time consumed in tests, expressed in minutes and seconds.

"Weight on machine at which elongation commenced.

Elongation—In order to get anything like satisfactory results from any experiments made to determine the percentage of elongation that any given sample of either iron or steel plates is capable of yielding, the samples ought to be at least six inches long, or better still, eight inches—the standard employed by the English and French governments. The samples should be rough polished on one side and ruled with lines at any convenient distance, say one-fourth inch apart. The elongation may easily be measured before or after breaking and the flow of metal observed at diff-

ent portions of the piece tested. The English Admiralty and Lloyd's Register both require that steel plates entering into the construction of ships and boilers shall stand an elongation of twenty per cent in an eight inch specimen. This would require an elongation of thirty-seven and a half per cent on a two inch specimen, as deduced from the Lloyd's experiments See page 72.

Iron boiler plate varies considerably, but will elongate from six to twenty per cent in samples of the same length as the above.

Reduction of area—When wrought iron and steel samples are broken to ascertain this tensile strength, the original area of cross section is always reduced and this reduction of area is a good index in determining the suitability of the material for boilers. When iron or steel plates are under high tension in a testing machine, the reduction of area will depend largely upon the inherent hardness or softness of the samples; thus, a soft fibrous iron will stretch and soon show a reduced area in which the fracture will occur. The amount of elongation and reduction of area will be found to be greater than if the iron had been of higher tensile strength. Hard specimens, either of iron or steel, stretch very little and in breaking do so suddenly with very little reduction of area. Soft steel elongates more than iron plates and will suffer a contraction amounting to from thirty to sixty per cent of original area.

The writer was shown by Mr. Atkinson several samples of "Sligo" iron, by Phillips, Nimick & Co., stamped fifty-seven thousand pounds and having an actual tensile strength of seventy-one thousand pounds, which showed after breaking an average contraction of area of thirty-five per cent.

Tenacity and ductility are so closely associated that separation is almost impossible, and the tendency of experts now is to require irons of a certain tensile strength to suffer a certain reduction of area before breaking, or when the elastic limit is reached. At a meeting of boiler plate manufacturers, held at Philadelphia, November, 1878, after a very intelligent discussion of this subject, it was

"Resolved, That in the judgment of this meeting, plates should not be used in a steamboat boiler that showed a contraction of area less than twelve per cent. We therefore recommend that all boiler plate, stamped with a tensile strain of under forty-five thousand pounds, should show contraction area of twelve per cent; forty-five thousand and under fifty thousand, should show fifteen per cent; fifty thousand and under fifty-five thousand, should show twenty-five per cent; fifty-five thousand and over should show 35 per cent."

In some tests made by Mr. Kirkaldy, in 1876, upon Essen and Yorkshire plates, one hundred and twenty-eight specimens were tested, with results as follows—specimens ten inches long in central portion, by two inches in width:

TABLE XXII.

	ESSEN.	YORKSHIRE.
Elastic stress.....	25,144 pounds.	27,477 pounds.
Ultimate stress.....	48,028 pounds.	45,515 pounds.
Stress for fractured area.....	74,542 pounds.	56,875 pounds.
Contraction of area.....	33.8 per cent.	18.6 per cent.
Extension at 30,000 pounds.....	1.94 per cent.	0.85 per cent.
Extension at 40,000 pounds.....	7.76 per cent.	6.41 per cent.
Extension ultimate.....	22.70 per cent.	14.80 per cent.

Elasticity is that property which all bodies have in a greater or less degree and by which they retain their form when acted upon by any force which tends to distort their original figure.

Elasticity is said to be *perfect* when a body acted upon by a force which distorts it will immediately and completely recover its original form, when the force is removed.

Elasticity is said to be *imperfect* when such a force permanently alters or changes the shape of the figure either wholly or in part.

The different kinds of elasticity are known by names corresponding to the different kinds of strains to which bodies can be subjected and are known under the several names—tension, compression, flexure and torsion.

The *elastic limit* of any material represents the load which it is capable of receiving before it becomes permanently fixed or set, and from which it will not recover when the load is removed. Thus, there are limits to tension, compression, flexure and torsion, beyond which the addition of a further application of weight or force will sooner or later lead to rupture.

Reference is made, not to sudden changes in stress and shocks, but to gradually increasing strains. This definition is theoretically worthless, for a limit so definite is not probable and much less is it proven.* Such investigators as Hodgkinson and Clark have observed that there are permanent changes of form under very small loads. At present we must be content with defining this limit with Fairbairn, as that stress below which the changes in form are approximately proportioned to the forces, while above this they increase much more rapidly.

All experiments, up to the present time, have shown that when the elastic limit is passed, the tensile resistance is considerably increased, while ductility and tenacity dimin-

*Weyrauch.

ish; the metal becoming brittle and having little power of resistance to shock. In experiments at the Woolwich Arsenal, an iron rod, four times ruptured by pull, gave the successive values of 3,520, 3,803, 3,978, 4,186.

"It is found by experiment that, up to the limit of elasticity, the displacements suffered by the molecules of the body are sensibly proportional to the stress which causes them, so that a double displacement is caused by a double straining force; a triple displacement by a triple straining force; and so on."*

The elastic limit is usually determined by weighing the force required to produce a perceptible and permanent change of form in the sample tested; this weight, divided by the area of the sample, gives the approximate elastic limit.

The elastic limit of wrought iron is generally taken at one-half its tensile strength. Experiments made at Washington on bars from five-eighths to two inches diameter show that for the particular grade of iron required for chain cables and for ship-building purposes generally, the elastic limit does not vary much from fifty-seven per cent of its tensile strength.

Tests made of rivet steel from the Edgar Thompson steel works show, on three-quarter inch bars turned down to one-half inch diameter, an elastic limit of 41,000 pounds, the sample having 64,000 pounds tensile strength; with twenty-nine per cent elongation in a three inch specimen and fifty per cent reduction of area at point of fracture. The carbon in this steel was 0.11 per cent.

For steel boiler plates from the same company having an area of .2232 ($.62 \times .36$), the elastic limit was 37,634 pounds, the tensile strength being 58,690 pounds.

*Anderson. Strength of Materials, page 4.

Percussion tests are seldom resorted to, for the reason that very few irons will stand such a test. It is sometimes employed in testing plates for ship building, and in all such tests the superiority of steel over iron plates is clearly shown. Percussion tests have been made by allowing a ball weighing nearly thirty-four hundred pounds to fall on the unsupported middle of steel and iron boiler plates from distances varying from five feet six inches to twelve feet high. The first blow from a height of five feet six inches cracked the iron plate, and these cracks were much extended when the plate was turned up and struck on the other side from a height of eight feet. With steel boiler plates the first blow was from five feet six inches high; this produced no flaw. The plate was then turned over and struck from a height of eight feet six inches; it was then turned over again and struck from a height of ten feet; and was again turned over and struck from a height of twelve feet, and still no crack or flaw found in it.

Bulging tests—These are seldom made, and so far as the writer is aware, are never required in any specifications for boiler plate. Experiments were made by Mr. Kirkaldy in 1875 to ascertain the resistance of plates to and the effects under bulging stress, and are tabulated in his report on Essen and Yorkshire wrought iron plates. Fifty-four specimens, each twelve inches diameter, were pressed into an aperture ten inches in diameter, the "bulger" being five inches in diameter and having a rounded end turned to a radius of five inches. The stress was gradually increased until the specimen was pushed through the aperture or until the specimen gave way either by cracking or bursting. These experiments were made on plates having a nominal thickness of three-eighths, one-half and five-

eighths of an inch. The three-eighths inch plates stood the test better than the latter, and are given in the following table taken from the report :

TABLE XXIII.

RESULTS OF EXPERIMENTS BY MR. KIRKALDY TO ASCERTAIN THE
RESISTANCE TO BULGING STRESS OF WROUGHT IRON PLATES.
NOMINAL THICKNESS THREE-EIGHTHS INCH.
PLATES UNANNEALED.

BRAND.	THICKNESS. INCH.	STRESS IN POUNDS BULGED, INCHES.					ULTIMATE.		EFFECTS.
		25,000.	50,000.	75,000.	100,000.	125,000.	BULGE. INCHES.	STRESS. POUNDS.	
Krupp.....	.44	0.81	1.34	1.75	2.12	2.58	3.28	139,940	Uncracked.
Krupp.....	.44	0.82	1.35	1.79	2.15	2.64	3.28	139,780	Uncracked.
Krupp.....	.44	0.82	1.36	1.80	2.16	2.67	3.26	137,560	Uncracked.
Mea .....	.44	0.82	1.35	1.78	2.14	2.63	3.27	139,093	
Farnley.....	.42	0.77	1.39	1.85	2.32	.....	3.24	116,810	Uncracked.
Lowmoor.....	.38	0.92	1.54	2.06	2.71	.....	3.20	102,780	Uncracked.
Bowling.....	.40	0.74	1.35	1.78	2.46	.....	3.22	114,420	Cracked.
Monkbridge.....	.37	0.86	1.47	1.97	2.51	.....	2.75	110,880	Burst.
Taylor's.....	.39	0.80	1.42	.....	.....	.....	1.84	54,720	Burst.
Cooper & Co.....	.38	0.85	1.47	.....	.....	.....	1.65	51,220	Burst.
Mea ⁿ.....	.39	0.83	1.44	.....	.....	.....	2.65	91,805	

The English Admiralty tests for irons entering into the construction of steam boilers are as follows:

TABLE XXIV.
TENSILE STRENGTH REQUIRED OF WROUGHT IRON SUPPLIED THE ENGLISH GOVERNMENT.

CLASS OF IRON.	HOW TESTED.	TENSILE STRAIN.	
		IN TONS (2,240 POUNDS) PER SQUARE INCH.	IN POUNDS PER SQUARE INCH.
BB or 1st class plate iron and sheet iron, $\frac{1}{2}$ inch thick and above.....	With the grain.....	22	49,280
	Against the grain.....	18	40,320
BB or 1st class boiler plate iron $\frac{1}{2}$ inch thick and above.....	With the grain.....	21	47,040
	Against the grain.....	18	40,320
B or 2d class plate or sheet iron.....	With the grain.....	20	44,800
	Against the grain.....	17	38,080
Angle, Bulb, T, \square or other iron of ordinary form.....	With the grain.....	22	49,280
Best merchant iron, BB bar iron, $\frac{1}{2}$ round, segmental. Fire bar iron.....	With the grain.....	22	49,280

Forge tests are made by bending the samples of iron over a corner of a cast iron slab, of which the edge is slightly rounded. The plates to be tested may be either hot or cold, and are tested both with and across the grain. The test consists in determining the angle through which the plate will bend without showing signs of fracture. This, of course, depends upon both the quality of the iron and the thickness of the plate.

The next table contains the requirements of the English government in forge tests, and will be found to be well adapted for testing American irons. The best American irons will stand a severer test than that required of the BB 21 ton T. S. English iron.

TABLE XXV.

SHOWING THE FORGE TESTS, BOTH HOT AND COLD, REQUIRED BY THE ENGLISH GOVERNMENT FOR PLATE AND SHEET IRONS.

KIND OF IRON TESTED.	POSITION OF THE GRAIN IN THE TEST.	PLATE IRON.					SHEET IRON.	
		COLD.				HOT.	COLD.	HOT.
		THICKNESS.				ALL THICKNESSES UP TO 1 INCH.		
		$\frac{1}{4}$ IN.	$\frac{1}{2}$ IN.	$\frac{3}{4}$ IN.	1 IN.			
T. S.								
Best Best, 21 tons.	Lengthwise..	70°	35°	25°	15°	125°	90°	125°
Best Best, 18 tons.	Crosswise.....	30°	15°	10°	5°	90°	40°	90°
Best, 20 tons.....	Lengthwise..	55°	30°	20°	10°	90°	75°	90°
Best, 17 tons.....	Crosswise.....	20°	10°	5°	.....	60°	30°	60°

The angles given in the above table is that through which the plate is bent, commencing at the horizontal, and is not the angle between the sides of the plate after it is bent.

Mr. Kirkaldy's experiments—The investigations of Mr. Kirkaldy, founded upon an elaborate series of experiments made by him on iron of every description and quality, led him to the following conclusions, among many others:

“1. The breaking strain does *not* indicate the quality, as hitherto assumed.

“2. A *high* breaking strain may be due to the iron being of superior quality, dense, fine and moderately soft, or simply to its being very hard and unyielding.

“3. A low breaking strain may be due to looseness and coarseness in the texture or to extreme softness, though very close and fine in quality.

"4. The contraction of area at fracture, previously overlooked, forms an essential element in estimating the quality of specimens.

"5. The respective merits of various specimens can be correctly ascertained by comparing the breaking strain *jointly* with the contraction of area.

"6. Inferior qualities show a much greater variation in the breaking strain than superior.

"7. Greater differences exist between small and large bars in coarse than in fine varieties.

"8. The prevailing opinion of a rough bar being stronger than a turned one is erroneous.

"9. Rolled bars are slightly hardened by being forged down.

"10. The breaking strain and contraction of area of iron plates are greater in the direction in which they are rolled than in a transverse direction. (The experiments show the difference to be about ten per cent)."

CHAPTER VI.

RIVETED JOINTS.

Effects in Punching Plates—Experiments on Drilled and Punched Holes—Experiments on Ordinary and Spiral Punching—Strength of Riveted Joints—Single Riveted, Hand, Steam and Hydraulic Riveting—Double Riveted Lap Joints—Single and Double Riveted Butt Joints—Experiments on Thick Steel Plates by Punching and Drilling—Loss Due to Punching—Experiments on Chain and Zig-Zag Riveting—Testing Rivets—Testing Stay Bolts—Shearing Tests of Rivet Iron and Steel—Steel Rivets—Proportions for Single Riveted Lap Joints—Double Riveting—Calking.

The only practical method of joining plates in the construction of boilers is by riveting. This is at best a very expensive and unsatisfactory way of making a joint, and the difficulties begin at the very outset by the loss of strength occasioned in punching the plates, and occurs by reason of,

1. A reduction of area through the line of rivet holes, and
2. By the disturbing influence of the punch on the remaining metal, still farther reducing its tensile strength.

The bad effects of punching are, in general, more apparent in steel than in iron plates. It has been observed that when ordinary mild steel plates, having a tensile strength of upwards of seventy thousand pounds, have been tested after punching and before annealing, there is a loss of strength variously estimated from five to forty per cent of the original plate, depending somewhat on the hardness and the thickness of the plate.

The observed changes in the material in the line of punched holes are, increased hardness, alteration of structure and loss of ductility.

From specimens tested, which had been cut from different portions of the same plate and in the same line of punched holes, there does not appear to be a uniform distribution of strain over the entire surface of the plate, but the disturbance of material is confined to within a very short distance around the hole, extending from one to three-sixteenths of an inch. This inference is drawn from the fact that by drilling and reaming out punched holes and then testing the plate, making proper allowance for the reduced area, no perceptible decrease of strength is noted.

TABLE XXVI.

SHOWING RESULTS OF EXPERIMENTS MADE TO ASCERTAIN THE EFFECTS PRODUCED BY DRILLED HOLES AND BY PUNCHED HOLES UNDER PULLING STRESS, KRUPP'S WROUGHT-IRON. TESTS BY MR. KIRKALDY.

	LENGTHWAY.		CROSSWAY.	
	DRILLED.	PUNCHED.	DRILLED.	PUNCHED.
Size of specimen—holes not deducted.....	8 x .44	8" x .44"	8" x .44"	8 x .44"
Size of specimen—gross area, square inches.....	3.52	3.52	3.52	3.52
Ultimate stress per square inch...	33,005 lbs.	28,006 lbs.	30,053 lbs.	24,329 lbs.
Ultimate stress—total.....	116,180 lbs.	98,580 lbs.	105,790 lbs.	85,640 lbs.
Difference, or loss per square inch.....	19,590 lbs.	26,534 lbs.	20,142 lbs.	26,101 lbs.
Difference or loss—per cent.....	37.2	45.6	40.1	51.7
Elongation of holes—fractured...	.34 inch.	.17 inch.	.27 inch.	.15 inch.
Elongation of holes—unfractured.....	.18 inch.	.05 inch.	.13 inch.	.03 inch.
Elongation of holes—total—inch.	.52	.22	.40	.18

TABLE XXVI—CONTINUED.

	LENGTHWAY.		CROSSWAY.	
	DRILLED.	PUNCHED.	DRILLED.	PUNCHED.
Elongation of holes—total—per cent.....	30.6	13.0	23.5	10.6
Appearance of fracture.....	Fibrous.	Fibrous.	Fibrous.	Fibrous.
Solid plate, ultimate stress per square inch	52,595 lbs.	54,540 lbs.	50,195 lbs.	50,430 lbs.

The drilled holes were made exactly the same size as those punched: Diameter 0.85 inch x 4 holes = 3.40 inches, or 42.5 per cent of the width of the specimen. All the specimens were unannealed.

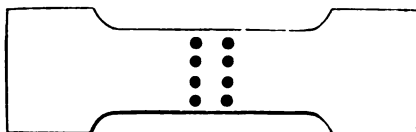


FIGURE 8.

The engraving, figure 8, represents the shape of the specimens tested, being 8 inches in width of central portion,

with the rows of rivet holes two and a half inches apart between their centers; the pitch of the four holes across the plate being two inches, the one row being to exhibit the elongation of the holes after the plate was pulled asunder, the other to show the shape of the holes without being fractured. The punched holes were conical, as usual, being larger on the exit than on the entrance side of the plate. Those drilled were all made exactly to the smaller size, and thus suitable for the same sized rivet.

It will be observed that in the first line of the table the space occupied by the rivet holes is not deducted as customary in making calculations on riveted joints, and that the gross and not the net area is stated. Mr. Kirkaldy's reason for doing so is, that it is better to give the total stress borne by the specimens of gross sectional area in pounds per square inch instead of the reduced area, so that any one can divide it by the net area, instead of the gross area, should they prefer to do so.

The strength of the solid plate, or that without the holes, was taken from other tests of the same material, and is given in the last line of the table, in order to facilitate comparisons. The difference in strength between that of the solid plate and that with the holes represents the loss due to the latter. As already shown in the foot note to the table, 42.5 per cent of the plate was removed in forming the four holes. The actual loss appears as follows: In the plate with drilled holes 37.2 per cent loss when tested lengthway of the plate, and 40.1 per cent when tested crossway; or a mean loss of 38.65 per cent for the two directions. In the plates with punched holes the loss, when tested lengthway of the plate, was 48.6 per cent and 51.7 per cent when tested crossway of the plate, showing a mean loss of 50.15 per cent for the two directions.

To summarize we have, then,

Loss due to punching, mean.....	50.15
Loss due to drilling, mean.....	40.01
Showing a mean loss of.....	10.14
per cent, due to punching over drilling.	*

The ultimate stress borne by a specimen is greatly affected by the hardness or softness of the material and by the shape of the specimen. The softer the material the more rapidly does its sectional area become reduced by the specimen stretching and consequently in the amount of stress sustained. When the breadth of a specimen is reduced to a minimum at one point, a greater resistance is offered to its stretching than when formed parallel for some distance; and as the stretching is checked so will also the contraction of area, and with it will be an increase in the ultimate stress.*

In all punched holes in boiler plates which the writer has measured, there has been the same conical taper resulting

* Kirkaldy.

from the use of a die larger than the punch. This is the common method of fitting punches and dies for boiler work, originating, doubtless, in a necessity for a larger die because of a lateral motion of the punch, due to the imperfect fitting of the slide to which the punch is secured. Then, afterwards, as punching machines were better built and had none of that lateral motion, the same practice of fitting punch and die continued, under the belief that it was necessary to good punching. The fact that some of the best examples of punching now on record was done in a machine in which the punch and die accurately fitted each other, shows that this matter of enlargement of the die may easily be overdone.

The ordinary clearance for five-eighths and three-quarters inch dies is nearly $\frac{1}{32}$ of an inch; the punch being made on size and the clearance allowed in the die.

Cold punched nuts, as for example, those made by Hoopes & Townsend, Philadelphia, when taken as examples of "commercial" punching as distinguished from experimental merely, are of considerable interest in this connection, owing to the entire absence of the conical holes spoken of in the preceding paragraph. It has already been shown in the table collated from Mr. Kirkaldy's experiments, that there is a loss in punching iron plates over drilling, approximating ten per cent. Hoopes & Townsend have long been of the opinion that if properly performed, punching does not weaken good iron farther than by the simple reduction of area. In order to determine the truth or falsity of this opinion they prepared

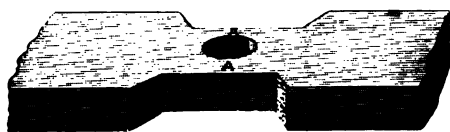


FIGURE 9.

a number of test pieces similar to that represented in figure 9. These were made of bar iron

$1\frac{3}{8} \times \frac{5}{8}$ inch, and one of each pair had a hole $\frac{3}{4}$ inch in

diameter drilled, and the other specimen the same sized hole punched in it. The specimens were then planed down next the hole, as represented in the engraving, so as to leave a thickness of three-eighths inch on each side of the hole. The other pairs had one-quarter, three-sixteenths and one-eighth inch respectively. These specimens were then broken by subjecting them to a tensile strain in one of Riehle Brothers' testing machines, with the following results:*

TABLE XVII.
STRENGTH OF PUNCHED AND DRILLED IRON BARS. HOOPES &
TOWNSEND.

THICKNESS OF BAR.	THICKNESS OUT- SIDE OF HOLE.	PUNCHED BAR BROKE AT	DRILLED BAR BROKE AT
$\frac{3}{8}$ inch.	$\frac{3}{8}$ inch.	31,740 pounds.	28,000 pounds.
$\frac{3}{8}$ inch.	$\frac{3}{8}$ inch.	31,380 pounds.	26,950 pounds.
$\frac{5}{8}$ inch.	$\frac{1}{4}$ inch.	18,820 pounds.	18,000 pounds.
$\frac{5}{8}$ inch.	$\frac{1}{4}$ inch.	18,750 pounds.	17,590 pounds.
$\frac{5}{8}$ inch.	$\frac{3}{16}$ inch.	14,590 pounds.	13,230 pounds.
$\frac{5}{8}$ inch.	$\frac{3}{16}$ inch.	15,420 pounds.	13,750 pounds.
$\frac{5}{8}$ inch.	$\frac{1}{8}$ inch.	10,670 pounds.	9,320 pounds.
$\frac{5}{8}$ inch.	$\frac{1}{8}$ inch.	11,730 pounds.	9,580 pounds.

From the engraving it will be seen that it was the portion of the iron immediately next to the hole, and which is usually supposed to be most affected by the action of punch or drill, which had to resist the strain. It will be seen that, in any case, the punched bars had the greatest strength, indicating that the punching had the effect of strengthening instead of weakening the iron. These experiments have given results just the reverse of similar experiments made on specimens of boiler plates; but

* These tests were undertaken at the suggestion of and were first published in the Railroad Gazette.

Messrs. Hoopes & Townsend argue that it is due, first, to the kind of material used, which is a tough and ductile iron, and second, to the method of punching. If a brittle and granular iron was used, the effect of the punching would be to crumble or disintegrate the iron in the immediate vicinity of the action of the punch; or if the punches and dies employed were so proportioned as to have a tendency to split open the bar, the metal around the hole would also be strained injuriously. But in manufacturing nuts they use a punch which fits accurately into the die, and the machines employed are heavy enough and made to work with sufficient accuracy so that the iron being punched is subjected to direct vertical pressure alone, without exerting any lateral or bursting strains in the iron. The effect is, that the metal is compressed and thus made more dense and stronger. That some such action takes place seems probable from the appearance of the holes in the nut, which are straight and almost as smooth as though they were drilled.



FIGURE 10.

Kennedy's patent spiral shearing punch—A eleven-sixteenths inch punch, the size used in ordinary five-eighths inch riveting, is shown full size in figure 10.

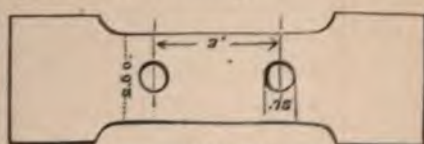
This punch derives its name from the fact that in its operation it performs its work in a circle, in the same manner that a shear does—in a straight line. Thus, to shear a hole two inches in diameter in a given plate of iron, is about the same as to shear off a bar of iron of the same thickness, a little more than six inches in width. It is well known that to cut off a given plate of metal with the blades of the cutter parallel, requires an amount of power and consequent strain upon the machine far beyond what it would

if the blades were only a few degrees angular to each other. This is just the difference between the flat and the "spiral shearing punch."

It would seem a matter of some surprise, then, that with this knowledge, and in view of the enormous and growing extent to which iron and steel are used, that so little change, to say nothing of improvement, has been made in the punching of holes. Some few attempts have been made in that direction, which are too familiar to need special notice; still, nothing has remained but the hard and costly and damaging method of the common flat punch. It is hard and expensive, because it not only requires a punching machine to be at least one-third heavier and stronger to meet the strain, but also requires at least fifty per cent more power to do the same work that can be done with the spiral punch. But the economy in power, the cost, and strain, and wear of machinery, which was the first object in the mind of the inventor, proves to be but a small part of the real value of the invention.

So serious and well known is the injury and weakening of the surrounding parts after punching thick steel plates and sometimes iron plates, has led to a prejudice against punching at all where the strength of the material is of importance, and, therefore, resort has generally been had to the tedious and costly process of drilling.

Experiments were made in steel plates cut to sample, as shown in figure 11, suitable for testing in a machine, with results as follows:



0.42 inch thick.
FIGURE 11.

Two holes were punched in each specimen, as seen in the cut, one with a flat punch and the other with a spiral punch. When tested, all the specimens broke through the hole punched with the flat punch.

In tests made to determine the relative amount of power required to operate the two kinds of punches, it was found that a seven-eighth inch "spiral punch" penetrated a five-eighth inch plate, at a pressure of twenty-two to twenty-five tons, while a seven-eighth "flat punch" in the same plate required thirty-three to thirty-five tons, thus showing a dead loss of ten tons of pressure on each hole, beside the additional strain and wear of machinery.

The following table supplies some interesting data in regard to punched plates, as well as a comparison of the two punches:

TABLE XXVIII.

RESULTS OF EXPERIMENTS MADE AT CREWE ON THE TENSILE STRENGTH
OF SAMPLES OF THE SAME PLATE PUNCHED WITH KENNEDY'S
SPIRAL AND ORDINARY PUNCHES RESPECTIVELY,
BY MR. F. W. WEBB.

DIAMETER OF HOLE.	BREAKING WEIGHT OF PLATE.		ELONGATION.		AREA OF PLATE UNDER TENSION.	REMARKS.
	ACTUAL.	PER SQUARE INCH.	ON TWO INCHES OF LENGTH ACROSS HOLES.	PER CENT.		
	POUNDS.	POUNDS.				
.885	45,350	63,752	.11	5.5	.7114	Punched with "ordinary" punch.
.885	45,000	60,318	.23	11.5	.7461	
.895	42,400	57,495	.14	7.0	.7375	
.89	37,050	51,287	.03	1.5	.7224	
.89	42,800	60,692	.06	3.0	.7052	
.90	45,150	61,047	.07	3.5	.7396	
.895	39,400	55,465	.09	4.5	.7032	
Mean	42,393	58,579	.104	5.2	.7236	

TABLE XXVIII—CONTINUED.

DIAMETER OF HOLE	BREAKING WEIGHT OF PLATE.		ELONGATION.		AREA OF PLATE UNDER TENSION.	REMARKS.
	ACTUAL.	PER SQUARE INCH.	ON TWO INCHES OF LENGTH ACROSS HOLES.	PER CENT.		
	POUNDS.	POUNDS.				
.885	45,850	63,285	.27	13.5	.7245	Punched with "Kennedy's spiral" punch.
88	48,000	67,672	.25	12.5	.7093	
88	46,200	63,584	.23	11.5	.7266	
.88	44,250	61,254	.12	6.0	.7224	
88	45,500	64,148	.26	13.0	.7093	
.895	47,600	66,084	.27	13.5	.7203	
.885	45,600	61,476	.09	4.5	.7418	
Mean	46,143	63,929	.21	10.6	.7220	Punched with both punches. Fracture occurred in every case thro' the "ordinary" punch hole.
.885	40,350	55,693	.21	10.5	.7245	
.89	41,800	59,274	.08	4.0	.7052	
.895	44,350	63,073	.24	12.0	.7032	
.885	45,400	62,664	.24	12.0	.7245	
.885	42,100	58,109	.24	12.0	.7245	
.89	45,450	62,915	.23	11.5	.7224	
.89	34,300	47,480	.07	3.5	.7224	
Mean	41,964	58,458	.19	9.3	.7181	

Strength of riveted joints—The first reliable data on the strength of riveted joints was given by Sir William Fairbairn in 1838, which was deduced from tests made with single and double riveted joints in plates of wrought iron one-quarter inch thick. The relative values given by him were,

Tensile strength of the solid plate.....	100
Tensile strength double riveted lap joint.....	70
Tensile strength single riveted lap joint.....	56

Since that time the percentages as given above have been in almost constant use by engineers and are still generally accepted. As differences in material, kind and number of rivets, as well as varieties of arrangement and spacing of rivet holes became more common, tests were also made from time to time with more or less varying results, some of which are presented in this chapter.

Mr. W. Bertram's experiments, as given by Mr. D. K. Clark in his Manual of Rules and Data, shows that for three thicknesses of specimens tested, viz, three-eighths, seven-sixteenths and one-half inch wrought iron plates, having a tensile strength of twenty tons (44,800 pounds) per square inch, that the averages of all the lap joints show that the three-eighths inch joint is the strongest, that the seven-sixteenth inch is nearly as strong, and that they are about one-quarter stronger than one-half inch lap joints, relatively to the thickness of the plate, thus:

TABLE XXIX.
COMPARATIVE STRENGTH OF RIVETED JOINTS.

THICKNESS OF PLATES.	$\frac{1}{2}$ INCH.	$\frac{7}{16}$ INCH.	$\frac{3}{8}$ INCH
Strength of plate, per cent.....	100	100	100
Strength of single riveted joint by hand..	40	50	60
Strength of double riveted joint by hand..	59	70	72

The test specimens were each four inches wide and contained two rivets each, three-quarters of an inch diameter, placed two inches apart, center to center. Three tests of each were made and averages taken for the numerical value of percentages as given.

The figures in the above table show that for single or double riveted joints, thin plates are to be preferred to thick ones.

Experiments by David Greig and Max Eyth, Leeds, England—In some tests of riveted joints made by these gentlemen (1879), in which each construction of joint was represented by four specimens of exactly the same dimensions, two being of steel and two of iron, one specimen of each material was of Brown's and one of Cammell's make. This distinction was made, not for the purpose of testing two different materials, but to get a fair average result. Tests of these two materials, made on samples two inches wide by three-eighths inch thick, gave an average breaking strain per square inch of solid plate as follows:

	TONS,	POUNDS,
Cammell's iron.....	21.9	49,056
Cammell's steel.....	24.0	53,760
Brown's iron.....	22.6	50,624
Brown's steel.....	27.6	61,824

This gives,

Average of iron.....	22.25	49,840
Average of steel.....	25.80	57,792

The iron specimens were invariably riveted together with iron rivets, the steel with steel rivets. The thickness of all plates was nominally three-eighths inch; the rivets, except in four cases, were nominally five-eighths inch, the holes being drilled eleven-sixteenths inch in diameter. The slight difference in the thickness of the plates was reduced by calculation in working out the experiments to a uniform thickness of three-eighths inch.

Test pieces were prepared, as shown in table XXX, to determine the relative value of punching and drilling. All the specimens were alike in their dimensions, two

pieces, six and a half inches wide, forming a single riveted lap joint, with four, five-eighths inch rivets, one and five-eighths inch pitch. The punched and drilled holes were of the same diameter, viz, $\frac{1}{8}$ inch. The die for the punch was $\frac{3}{4}$ inch diameter, or the usual $\frac{1}{32}$ inch clearance. The conical hole produced by punching measured at the top 0.708 inch and at the bottom 0.790 inch, there being no measurable difference between iron and steel in this respect. Four of these specimens were of iron, two being drilled and two punched, all steam riveted. In the punched specimens the conical holes were placed with their smaller ends in contact. Of the two drilled specimens, one broke through the plate, the other sheared in rivets. The average strength of the same proved to be 50.4 per cent of the strength of the solid plate.

TABLE XXX.
STRENGTH OF LAP JOINTS, SINGLE RIVETED.

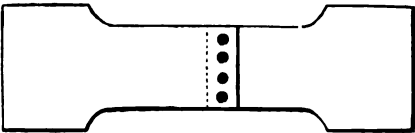


FIGURE 12.

PLATE SIX AND ONE-HALF INCHES WIDE, THREE-EIGHTHS INCHES THICK, FOUR FIVE-EIGHTHS RIVETS, ONE AND FIVE-EIGHTHS INCH PITCH.

Greig and Eyth.

DESCRIPTION OF SPECIMEN.	AVERAGE BREAKING STRAIN OF SPECIMEN IN POUNDS.		BREAKING STRAIN OF SOLID PLATE PER INCH OF WIDTH, IN POUNDS.		BREAKING STRAIN OF SPECIMEN PER INCH OF WIDTH, IN POUNDS.		STRENGTH OF SEAM PER CENT OF SOLID PLATE.		STRAIN PER RIVET, IN POUNDS.		SHEARING RESISTANCE OF RIVET IRON PER RIVET, IN POUNDS.		STRENGTH OF SPECIMEN, PER CENT OF NORMAL STRENGTH OF MATERIAL..	
Iron plate, drilled holes.....	61,330	18,700	9,438	50.4	16,325	15,810	84.1	108						
Iron plate, punched holes..	49,400	18,700	7,600	40.6	.....	.....	75.5	.....					

TABLE XXX—CONTINUED.

DESCRIPTION OF SPECIMEN.	AVERAGE BREAKING STRAIN OF SPECIMEN IN POUNDS.	BREAKING STRAIN OF SOLID PLATE PER INCH OF WIDTH, IN POUNDS.	BREAKING STRAIN OF SPECIMEN PER INCH OF WIDTH, IN POUNDS.	STRENGTH OF SEAM PER CENT OF SOLID PLATE.	STRAIN PER RIVET, IN POUNDS.	SHEARING RESISTANCE OF RIVET IRON PER RIVET, IN POUNDS.	STRENGTH OF SPECIMEN, PER CENT OF NORMAL STRENGTH OF MATERIAL.
plate, drilled holes.....	79,800	21,700	12,300	56.6	19,950	18,440	PLATES RIVETS. 108
plate, punched holes and annealed.....	84,700	21,700	12,950	59.6	21,175	18,440	..... 115
plate, punched holes and unannealed.....	84,900	21,700	13,060	60.2	21,225	18,440	..... 115

Second Series of Tests for Different Modes of Riveting.

DESCRIPTION OF SPECIMEN.	AVERAGE BREAKING STRAIN OF SPECIMEN IN POUNDS.	BREAKING STRAIN OF SOLID PLATE PER INCH OF WIDTH, IN POUNDS.	BREAKING STRAIN OF SPECIMEN PER INCH OF WIDTH, IN POUNDS.	STRENGTH OF SEAM PER CENT OF SOLID PLATE.	STRAIN PER RIVET, IN POUNDS.	SHEARING RESISTANCE OF RIVET IRON PER RIVET, IN POUNDS.	STRENGTH OF SPECIMEN, PER CENT OF NORMAL STRENGTH OF MATERIAL.
hand riveted	56,550	18,700	8,700	46.5	.....	.....	PLATES RIVETS. 82.5
steam riveted.....	61,850	18,700	9,515	50.9	16,775	15,810	84.6 106
hydraulic riveted.....	64,350	18,700	9,900	53.9	16,875	15,810	89.6 107
hand riveted.....	69,800	21,700	10,730	49.4	17,450	18,440	..... 94.9
steam riveted.....	82,600	21,700	12,707	58.5	20,600	18,440	..... 112
hydraulic riveted.....	76,700	21,700	11,800	54.4	19,175	18,440	..... 10

The practical conclusions to be drawn from the above are, that the tensile strength of iron plates, single riveted, range from 40.6 to 53.9 per cent, and for steel from 56.6 to 60.2 per cent.

In the experiments the hand riveted iron specimens broke through the plate, showing the seam to have a strength of 46.5 per cent of the solid plate, and the iron section to break with 82.5 per cent of its normal breaking strain. Of the iron specimens riveted by hydraulic and steam power, one broke in the plate and the other sheared the rivet in each case. The strength of the seam proved to be 50.9 per cent of the solid plate for steam, 53.9 per cent for hydraulic pressure; the breaking strain of the iron being for steam 84.6 per cent and for hydraulic pressure 89.6 per cent of its normal breaking strain. Here, then, hydraulic riveting has come out distinctly superior to steam riveting, its quiet action no doubt injuring the material less than the shock given by the steam riveter. Hand riveting, of course, is left far behind by the two other methods.

In regard to the tests on steel plates, all the specimens (six) broke by the shearing of the rivets. Hand, steam and hydraulic pressure gave respectively 49.4, 58.5, 54.4 per cent for the strength of seam as compared with the solid plates, and the rivets broke respectively with 94.9, 112 and 107 per cent of their normal shearing strain. Here, then, hydraulic riveting has come out second best, the proportion corresponding remarkably well with previous experiments concerning a single rivet. The fact then seems to be that the plate, especially if soft, is much less injured by hydraulic riveting, and that this method has, therefore, a decided advantage where the plate is the weaker part, but that the rivet itself is stronger when put in by the steam riveter (at least by the machines used for these experiments), owing, probably, to the greater compactness of the rivet material obtained by the sudden shock.

TABLE XXXI.

STRENGTH OF LAP JOINTS—DOUBLE RIVETED PLATE, SEVEN AND A HALF INCHES WIDE, THREE-EIGHTHS INCH THICK.

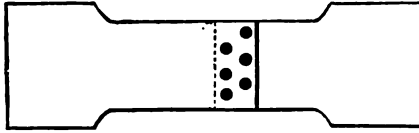


FIGURE 13.

Greig and Eyth

DESCRIPTION OF SPECIMEN.	AVERAGE BREAKING STRAIN OF SPECIMEN IN POUNDS.	BREAKING STRAIN OF SOLID PLATE PER INCH OF WIDTH, IN POUNDS.	BREAKING STRAIN OF SPECIMEN PER INCH OF WIDTH, IN POUNDS.	STRENGTH OF SEAM PER CENT OF SOLID PLATE.	STRAIN PER RIVET IN POUNDS.	SHEARING RESISTANCE OF RIVET IRON PER RIVET, IN POUNDS.	STRENGTH OF SPECIMEN, PER CENT OF NOMINAL STRENGTH OF MATERIAL.	
							PLATES	RIVETS.
Iron plate, six $\frac{5}{8}$ rivets (flat zigzag).....	90,700	18,700	12,093	64.6	15,733	15,810	113	99.4
Steel plate, six $\frac{5}{8}$ rivets (flat zigzag).....	113,300	21,700	15,107	70.0	18,883	18,440	.....	102.
SECOND SERIES.								
Iron plate, eight $\frac{3}{4}$ rivets (sharp zigzag).....	83,100	18,700	11,086	59.2	.....	.....	104	.....
Steel plate, eight $\frac{3}{4}$ rivets (sharp zigzag).....	102,460	21,700	13,661	62.9	.....	.....	114	.....

Iron plates have iron rivets; steel plates steel rivets.

These tests show a reduction in strength of seam by increasing the number of rivets in a seven and a half inch plate, from six to eight, and also their diameters from five-eighths to three-quarters inch. The plate containing the six rivets, five-eighths inch diameter, had two and a half inch centers of rivets lengthwise of the seam, the second row of rivets being in a line one inch distant, making the diagonal centers of rivets one and five-eighths

One of the iron specimens broke through the plates, the fracture following a zigzag line through the rivet holes; the other sheared the rivets. The strength of the seam was 64.6 per cent the full strength of the plate. In the first case (zigzag fracture), the section of the plate along the line of fracture broke with 113 per cent of its normal tearing strain. The steel samples broke through the rivets, the latter showing a shearing resistance only two per cent above the normal. This reduction of strength, as compared with former test pieces, is caused by the absence of bending of the joint, owing to the double row of rivets keeping the plates more rigidly in line. The strength of the seam was the highest obtained, being 70 per cent of the solid plate.

In the second series of tests in table XXXI, the test specimens were of the same dimensions as the first, viz, seven and a half inches wide, three-eighths inch thick, the number of rivets being increased to eight and their diameters to three-quarters of an inch. The pitch of these rivets was one and seven-eighths inch lengthwise of the seam, and one and seven-eighths inch centers of rivets to the second row, or equidistant in any direction. Although the joint is very rigid, it is rather weak in the plate against direct tensile strain and was sure to break in a straight line across the rivets. Its strength proved to be 59.2 of the solid plate for iron and 62.9 per cent for the steel specimens, showing again the great advantage gained by the effect of a double row of rivets in preventing the bending of the joints under stress.



TABLE XXXII.
STRENGTH OF BUTT JOINTS, SINGLE AND DOUBLE RIVETED, SINGLE AND TWO COVERS, IRON AND STEEL PLATES, THREE-EIGHTHS INCH THICK, RIVETS FIVE-EIGHTHS OF AN INCH IN DIAMETER.

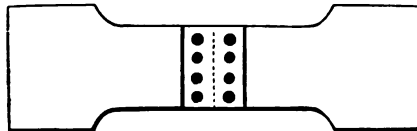


FIGURE 14.

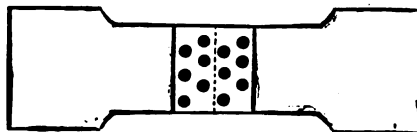


FIGURE 15.

Greig and Eyth.

DESCRIPTION OF SPECIMEN.	AVERAGE BREAKING STRAIN OF SPECIMEN IN POUNDS.	BREAKING STRAIN OF SOLID PLATE PER INCH OF WIDTH, IN POUNDS.	BREAKING STRAIN OF SPECIMEN PER INCH OF WIDTH IN POUNDS.	STRENGTH OF SEAM PER CENT OF SOLID PLATE.	STRAIN PER RIVET, IN POUNDS.	SHEARING RESISTANCE OF RIVET IRON PER RIVET, IN POUNDS.	STRENGTH OF SPECIMEN PER CENT OF NORMAL STRENGTH OF MATERIAL.	
							PLATES	RIVETS
Iron plate, $6\frac{1}{8}$ inches wide, single cover, single riveted, four $\frac{5}{8}$ inch rivets in each plate. Figure 14.....	58,000	18,700	8,923	46.6			82.3	
Steel plate, $6\frac{1}{8}$ inches wide, single cover, single riveted, four $\frac{5}{8}$ inch rivets in each plate. Figure 14.....	78,800	21,700	12,123	55.8	19,700	18,440	107	
Iron plate, $7\frac{1}{8}$ inches wide, single cover, double riveted, six $\frac{5}{8}$ rivets in each plate. Figure 15...	78,000	18,700	10,400	55.6			103	
Steel plate, $7\frac{1}{8}$ inches wide, single cover, double riveted, six $\frac{5}{8}$ rivets in each plate. Figure 15...	110,750	21,700	14,766	68.0	18,346	18,440		104

TABLE XXXII—CONTINUED.

DIMENSIONS OF SPECIMEN.	AVERAGE BREAKING STRAIN OF SPECIMEN IN POUNDS.	BREAKING STRAIN OF SOLID PLATE PER INCH OF WIDTH, IN POUNDS.	BREAKING STRAIN OF SPECIMEN PER INCH OF WIDTH, IN POUNDS.	STRENGTH OF BEAM PER CENT OF SOLID PLATE.	STRAIN PER RIVET, IN POUNDS.	SHEARING RESISTANCE OF RIVET IRON PER RIVET, IN POUNDS.	STRENGTH OF SPECIMEN PER CENT OF NORMAL STRENGTH OF MATERIAL.	
							PLATES	RIVETS.
Iron plate, 6½ inches wide, two covers, single riveted, four ⅝ inch rivets in each plate. Figure 14.....	76,350	18,700	11,746	62.7	.....	.....	108	.....
Steel plate, 6½ inches wide, two covers, single riveted, four ⅝ inch rivets in each plate. Figure 14.....	95,450	21,700	13,100	60.4	.....	.....	117	.....
Iron plate, 7½ inches wide, two covers, double riveted, six ⅝ inch rivets in each plate. Figure 15.....	89,150	18,700	11,886	63.5	.....	.....	118	.....
Steel plate, 7½ inches wide, two covers, double riveted, six ⅝ inch rivets in each plate. Figure 15.....	110,500	21,700	14,740	68.0	.....	.....	126	.....

Iron plates have iron rivets, steel plates steel rivets.

Figure 14 is a representation of the two test specimens given in the first two lines in the table, being single riveted butt joints, with a cover plate on one side only, the four five-eighths inch rivets being arranged exactly as in the lap joints given in table XXX. The result was unfavorable. The cover (which was of the same strength as the plate) bent readily, as shown in figure 16.

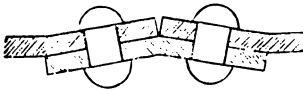


FIGURE 16.

The iron specimens gave way in the plate, the seam showing a strength of 46.6 per cent of the solid plate; that is to say, not higher than the ordinary lap joints. The steel samples sheared through the rivets, their strength being 55.8 per cent of the solid plate. Experiments made on plates seven and a half inches wide, with a single cover and double riveted, the arrangement of the rivets being the same as the double riveted lap joints already described, the iron specimens gave even less favorable results than the corresponding lap joints, proving conclusively that a butt joint of the ordinary description, viz, with one cover of the same thickness as the plate, has scarcely any advantage over the ordinary lap joint. The results are very different in butt joints with double covers, of which eight samples were prepared, four being single riveted and four double riveted. The shearing resistance of the rivets is by this construction at once doubled, as the two sections have to be sheared to break a rivet. All specimens, therefore, broke through the plates. But the tensile resistance of the plates was also greatly increased, partly because the construction prevents all bending of the plates, partly because a considerable amount of frictional resistance between the plates is gained. Thus, in all these cases, though the plates broke, the strength of the seam was from 60 to 68 per cent of the strength of the solid plate, and the breaking strain of the fractured section rose in the last case to 126 per cent of the normal breaking strain of the steel.

From what has already been said it appears that, for three-eighths inch iron plates the difference between punched and drilled holes is about ten per cent in favor of the latter, as compared with the strength of solid plate. For steel the difference between drilled and punched holes in unannealed plates is about four per cent in favor of drilling, and three per cent if the plates are annealed after punching. A difference so slight as this would hardly

“pay” on the one hand for the expense of drilling, nor on the other for the expense of annealing; if plates are properly annealed at the manufactory there ought to be no further necessity for annealing in ordinary boiler construction in which one-quarter, five-sixteenths and three-eighths inch steel plates are used, having a tensile strength of sixty to sixty-five thousand pounds, and will stand the bending and temper tests already described.

Mr. Boyd's experiments on thick steel plates—The effect of punching thick plates is different from what has been described in the pages immediately preceding, as fully shown in the abstract of results obtained by Mr. William Boyd, Newcastle-on-Tyne, England. In fourteen samples of steel boiler plates tested by Mr. Boyd, the average tensile strength was found to be 28.7 tons (64,288 pounds) per square inch, and with one exception exhibited a remarkable uniformity, showing that regularity of quality is now obtainable in a large specification of steel plates, without practical difficulty.

Elasticity is lost at an early point, viz, at an average of 16.6 tons (37,184 pounds) per square inch, equal to 58 per cent of the ultimate breaking strain. Elasticity also commences early, for it was quite perceptible when the specimen tested had a strain of but eleven tons (24,640 pounds) per square inch of section.

In endeavoring to arrive at a fair estimate of the amount of stretch in relation to the length, it was thought best to eliminate all the short specimens as not affording reliable data. Taking four specimens six and a half inches long, three specimens seven and a quarter inches long and two specimens twelve inches long, the ultimate stretch or elongation was found to be 26.5 per cent of the length of the specimen.

TABLE XXXIII.

EXPERIMENTS ON PUNCHED AND DRILLED HOLES IN THICK STEEL
BOILER PLATES, BY WILLIAM BOYD.

		DESCRIPTION.	SIZE.	SECTIONAL AREA.	DIAMETER OF HOLE.	BROKE AT TONS.	STRESS PER SQ. IN TONS.	MEAN STRESS PER SQUARE INCH.
1st Series.	1	Steel, punched holes.....	$8\frac{3}{4} \times \frac{11}{16}$	3.98	$1\frac{1}{8}$	75	18.8	18.1
	2	Steel, punched holes.....	$8\frac{3}{4} \times \frac{11}{16}$	3.98	$1\frac{1}{8}$	70	17.4	
	3	Steel, drilled holes.....	$8\frac{1}{32} \times \frac{11}{16}$	4.01	$1\frac{3}{32}$	110	27.4	
	1	Steel, punched holes.....	$8 \times \frac{13}{16}$	4.72	$1\frac{3}{32}$	103	21.8	21.15
	2	Steel, punched holes.....	$8 \times \frac{13}{16}$	4.72	$1\frac{5}{32}$	97	20.5	
	3	Steel, punched, annealed.	$7\frac{11}{16} \times \frac{13}{16}$	4.70	$1\frac{3}{32}$	142	30.2	29.5
	4	Steel, punched, annealed.	$8 \times \frac{13}{16}$	4.72	$1\frac{3}{32}$	136	28.81	
	5	Steel, drilled holes.....	$8 \times \frac{13}{16}$	4.72	$1\frac{3}{32}$	146	30.9	

The first two specimens in the first series were punched holes, and show a mean breaking strain of 18.1 tons (40,544 pounds) per square inch; taking twenty-eight tons (62,720 pounds) as the breaking strain of solid steel plate, this shows a loss of strength equal to 35.36 per cent. In the last experiment of the first series, the holes were drilled, and the specimen broke at 27.4 tons per square inch, showing a loss of only 2.15 per cent.

Mr. Boyd next desired to ascertain whether the process of heating or annealing the plates in the furnace had any effect; for, in practice, all the shell plates of this thickness were so treated, being put into a plate furnace and heated to a dull red heat before being bent in the rolls to the required diameter. The second series in the table exhibits the results of these experiments. In the first two specimens the holes were punched and broke at a mean strain of 21.15 tons (47,376 pounds) per square inch. In the

second pair, the holes were also punched, but the specimens were afterward annealed in the manner described, and the mean breaking strain rose to 29.5 tons (66,080 pounds) per square inch, showing a result fully equal to that allowed per square inch for solid plate. In the fifth plate the holes were drilled, and the breaking strain was 30.9 tons (69,216 pounds) per square inch. If, then, the mean breaking strain of these last three specimens be taken at 30.2 tons (67,648 pounds) per square inch, and the breaking strain of the first two specimens with punched holes as 21.15 tons (47,378 pounds) per square inch, a loss of 29.97 per cent is shown in this plate (all the five samples being cut out of one plate, as being due to the operation of punching the holes.

The results of Mr. Boyd's experiments on thick plates seem to show,

1. "That steel is not injured by drilling.
2. "That it is injured to the extent of about 33 per cent by punching; but,
3. "That the nature of the material is restored entirely, if the plate be heated and annealed after punching and allowed gradually to cool out.

In describing the effects consequent on punching holes in steel plates for use in boiler making and for other similar purposes, and comparing their strength and adaptability with plates having drilled holes, it becomes a matter of the highest importance to notice the quality of the steel submitted to each of these processes. The highly carbonized plate, or one that is characterized by hardness and density of substance, reveals in its fracture a very fine, bright, granular appearance. This, when closely inspected, is found to contain a well arranged and well developed mass of particles, each of which, by the laws of cohesion and affinity, will closely adhere to its fellow, and being so highly carbonized and pure, will offer immense resistance and

over all the time there is not a leading fracture in any part of the plate. But the exceeding hardness of the particles prevents what is most desirable in a plate subjected to varied strains and fitful action, namely, a certain amount of elasticity, combined with capability of elongation. Thus, while the more inferior particles of a common plate, under heavy strains, have a tendency to overlap each other and blend together, the reverse is the case with the hard plate, the particles of which, refusing to elongate and overlap each other, continue to hold intact their more perfect forms till they suddenly part. This is evident in the process of punching, for the pressure of the punch and die on the metal disturbs and disarranges the particles in the immediate locality of the hole and creates internal—though imperceptible—fractures.

The writer is of the opinion, from the results of experiments made on one-quarter and five-sixteenths steel boiler plates, below seventy thousand pounds, that the loss by punching does not affect the strength of the plate sufficiently to warrant the extra trouble and expense of annealing, especially if the die is somewhat larger than the punch, so that the hole shall be slightly conical. The heat from the hot rivet will then sufficiently anneal the plate.

Experiments by Mr. Boyd on chain and zigzag riveting— In order to ascertain experimentally whether there was an important difference in strength between chain and zigzag riveting, Mr. Boyd had test specimens of each, prepared similar to figures 17 and 18.



FIGURE 17. ZIGZAG RIVETING.

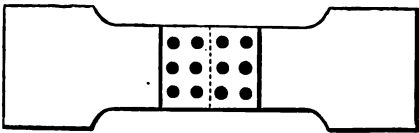


FIGURE 18. CHAIN RIVETING.

Both test specimens were cut from a steel boiler plate, eleven-sixteenths of an inch thick. The following table gives the particulars of the test:

TABLE XXXIV.

EXPERIMENTS MADE ON STEEL BOILER PLATES TO DETERMINE THE
RELATIVE TENSILE STRENGTH OF CHAIN AND ZIGZAG
RIVITED JOINTS, ARRANGED FROM DATA FUR-
NISHED BY MR. BOYD.

	STYLE OF RIVETING.	
	CHAIN.	ZIGZAG.
Width of test specimen.....	12 inches.	12 inches.
Thickness of test specimen.....	$\frac{11}{16}$ inch.	$\frac{11}{16}$ inch.
Thickness of side plates (one on each side),	$\frac{1}{2}$ inch.	$\frac{1}{2}$ inch.
Length of side plate.....	11 $\frac{1}{2}$ inches.	10 inches.
Rivets, diameter.....	1 $\frac{1}{8}$ inch.	1 $\frac{1}{8}$ inch.
Rivets, spacing C to C across the specimen,	4 inch.	4 inches.
Rivets, spacing C to C of rows.....	2 $\frac{3}{4}$ inches.	2 inches.
Area of solid plate.....	8 $\frac{1}{4}$ inches.	8 $\frac{1}{4}$ inches.
Net sectional area of plate through rivet holes.....	6.057 inches.	6.057 inches.
Percentage of net to original area.....	73.41 per ct.	73.41 per ct.
RESULTS.		
Total strain at which specimens broke	{ 174 tons, 389,760 lbs.	{ 140 tons, 313,600 lbs.

TABLE XXXIV—CONTINUED.

	STYLE OF RIVETING.	
	CHAIN.	ZIGZAG.
Excess of strength in the chain riveting...	{ 34 tons, 76,160 lbs.	
Relative strength of joint and solid plate, at 26 tons (58,240 lbs.) per square inch,	81.11 per ct.	65.32 per ct.
Relative strength of joint and solid plate, at 28 tons (62,720 lbs.) per square inch,	75.32 per ct.	60.66 per ct.

It will be observed that the chain riveted joint is 24.28 per cent stronger than the zigzag riveting, which raises the interesting question whether it is not to be preferred, even though the area of solid plate left untouched by rivet holes remains the same.

There has long been a misconception as to the real strength of chain riveted over single riveted joints, and an opinion has obtained in the minds of many engineers that a chain joint, similar to that shown in figure 18, is no stronger than the single riveted joint, as in figure 14, the argument being that the maximum strength of the seam must be that of the weakest section, and, hence, through the line of rivet holes; it being either denied or doubted that by simply extending the plate and inserting a second row of rivets should add to the strength of the first row, nor to the strength of the joint, and that when a sufficient strain is brought to bear upon the joint, it would be quite as likely to break through the first row of rivet holes as though the second row were not there. This notion in regard to chain joints is entirely disproved by what has already been shown in Mr. Boyd's experiments, and by results taken from those of Mr. Bertram, and given in table XXXV.

TABLE XXXV.
SHOWING THE COMPARATIVE STRENGTH OF SINGLE RIVETED AND DOUBLE
CHAIN RIVETED JOINTS ON WROUGHT IRON BOILER PLATES OF DIF-
FERENT THICKNESSES, EACH HAVING AN AVERAGE TENSILE
STRENGTH OF TWENTY TONS (44,800 POUNDS) PER SQUARE INCH. FROM
EXPERIMENTS BY MR. BERTRAM.

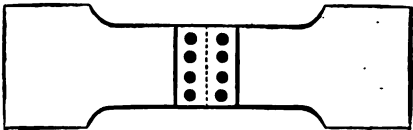


FIGURE 19.

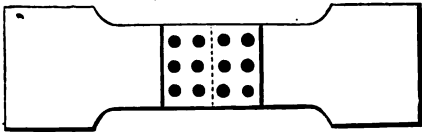


FIGURE 20.

DESCRIPTION OF JOINT.	NET ULTIMATE STRENGTH OF JOINT.			
	$\frac{1}{2}$ INCH PLATES.	$\frac{7}{16}$ INCH PLATES.	$\frac{3}{8}$ INCH. PLATES.	AVERAGE FOR THE THREE PLATES.
	PER CENT.	PER CENT.	PER CENT.	PER CENT.
Entire plate.....	100	100	100	100
Single riveted, hand, fig- ure 19.....	40	50	60	50
Single riveted, machine, figure 19.....	40	54	52	49
Double riveted (chain). Figure 20.....	59	70	72	67

We thus have an average gain by chain riveting ove
single riveting in

One-half inch plates of.....	19 per cent.
Seven-sixteenths inch plates of.....	18 per cent.
Three-eighths inch plates of.....	16 per cent.

These joints were all made with three-quarter inch rivets, arranged in the specimens at two-inch centers.

Testing rivets—The strength of a riveted joint depends so much on the strength of the rivets which enter into it, that it is of the utmost importance to know the quality of the materials of which they are made, before putting any work on them. One of the simplest and at the same time a severe test, is to upset a rivet on an anvil under a heavy hammer, say to one-half its original length and without splitting it. The writer has employed this test in determining the quality of supplies, and finds that specimens selected at random, and which will stand this test, have usually all the other qualities of a good rivet; but as the strain brought upon rivets is that of shearing, tests should be made to determine the resistance to the separation of the rivet at the line of plates composing the joints, which may be either single or double shear, the former being the ordinary practice in this country, the latter the exception.

Single shearing is clearly shown in figure 21, which represents a rivet in a single riveted joint, undergoing separation.



FIGURE 21.

Mr. Wm. H. Shock, chief engineer U. S. N., made some shearing tests of iron for stay bolts with results as given below. This quality of iron is not as high as that usually employed in the manufacture of rivets, but still of good quality. The iron was made up into bolts with nuts, instead of being riveted into the testing plates, as is the usual practice. There were sixty of these bolts in all; twelve

TABLE XXXVI.

RESULTS OF EXPERIMENTS ON SHEARING STRAINS OF IRON BOLTS, BY
WILLIAM H. SHOCK, CHIEF ENGINEER, UNITED STATES NAVY.

Mean of both sets, $\frac{40817}{2} + \frac{38984}{2} = 39,900$.

The tensile strength of rivet and stay bolt iron will average higher than what is known as the best merchant iron, or that employed in the experiments of Mr. Shock. Many manufacturers make a special grade of iron for this purpose, some of which is maintained with great uniformity of quality. The tensile strength of iron or mild steel is not in all cases a correct guide as to the shearing resistance of the same piece; the common belief is, that they closely approximate each other. In the experiments of Messrs. Grieg and Eyth to determine this, in which two

sets of tests were made on both iron and steel, one to determine the tensile strength and the other to determine the shearing resistance of specimens taken from the same bar, the following average results were obtained:

TABLE XXXVII.
TENSILE TESTS OF RIVET IRON.

DIAMETER $\frac{5}{8}$ IN. = 0.307 SQ. IN. AREA.	STEEL.	IRON.
Breaking strain per section.....	19,869 pounds.	15,320 pounds.
Breaking strain per square inch....	64,579 pounds.	49,795 pounds.
Reduction of area, per cent.....	30.1	42.03
Elongation in 10 in. (orig. length)..	2.06 inches.	2.78 inches.

It will be observed that the tensile resistance of the steel is thirty per cent higher than the iron.

In the shearing tests of rivet iron and steel the diameter of the bars of rivet material were five-eighths inch; the area sheared through being $2 \times 0.3068 = 0.6136$ square inch.

	STEEL.	IRON.
Average shearing strain.....	30,486 lbs.	26,130 lbs.
Shearing strain per square inch..	49,683 lbs.	42,582 lbs.

These specimens were subjected to a double shearing strain in a simple apparatus, consisting merely of two three-eighths inch steel plates, fixed at a distance of three-eighths of an inch apart, so as to permit another three-eighths inch steel plate to slip in between the first two. These three plates were then perforated by a five-eighths inch drill and the specimen inserted in the hole; the two outside plates were then pulled by the testing machine in one direction and the plate between them in the other. Thus the specimens were in double shear, two sections being sheared clean through during the process of testing.

When tested in this way the steel rivets showed an average shearing resistance of 49,683 pounds per square inch, the iron of 42,582 pounds. Thus the shearing resistance of the steel was only 17 per cent higher than that of the iron. This explains how it is that in the test pieces representing riveted seams, given elsewhere in this chapter, that the steel specimens, as a rule, broke by shearing of the rivets and the iron by tearing the plate through the holes. It is also worth noting how far from the truth is the rule so frequently adopted, which assumes the tensile resistance of iron or steel to be about equal to the shearing resistance, at any rate in cases of double shear. In the present case the latter proved far less than the former; in the case of iron by 16 per cent, in the case of steel by 28 per cent, showing besides that the shearing resistance does not bear any fixed proportion to the tensile resistance.

The shearing resistance of the bars of iron and steel having been concluded, Messrs. Greig and Eyth then investigated the shearing resistance of rivets actually formed. For this purpose three steel plates (three-eighths inch thick) were riveted together in a manner analogous to that already described. The rivets intended to be tested were so-called five-eighths inch rivets, inserted into drilled holes of eleven-sixteenths of an inch in diameter. It was thought of some interest to ascertain the effect of different methods of riveting. These are given below:

TABLE XXXVIII.

SHEARING RESISTANCE OF IRON AND STEEL RIVETS, FIVE-EIGHTHS OF AN INCH IN DIAMETER.

Greig and Eyth.

MATERIAL OF RIVET.	METHOD OF MAKING THE RIVET.	SHEARING STRAIN OF SPECIMEN.	AVERAGE.	AVERAGE SHEARING STRAIN PER SQUARE INCH
		POUNDS	POUNDS.	POUNDS.
Iron.....	Hand riveting.....	33,488	34,630	46,646
Iron.....	Hydraulic riveting..	34,552		
Iron.....	Steam riveting.....	35,862		
Steel	Hand riveting.....	42,392	43,646	58,790
Steel.....	Hydraulic riveting..	43,288		
Steel.....	Steam riveting.....	45,696		

Holes drilled eleven-sixteenths of an inch in diameter. The actual section sheared through, two circles of eleven-sixteenths of an inch in diameter, or 0.7424 square inch.

The shearing resistance of these six rivets, as will be seen, showed a considerable increase over that of the simple bar not yet formed into a rivet, which is due partly to the increased sectional area of the material, which now fills an eleven-sixteenths inch hole, and partly to the friction between the plates held together by the rivets. It should be noted, however, that this increase is much greater in the case of steel than of iron.

The following table gives the results of experiments made on twelve specimen rivets (steel), having a nominal diameter of five-eighths of an inch, the actual section sheared through being two circles of eleven-sixteenths of an inch in diameter, or 0.7424 square inch. This series of tests were undertaken because of the striking regularity with which the experiments recorded in table XXXVIII showed as to the relative strength of hand, hydraulic and

steam riveting, both in iron and steel. Four different machines were employed, in which the pressures on the rivet heads were as follows:

Steam riveter.....	82,380 lbs.
Tweddell's stationary machine.....	86,360 lbs.
Tweddell's portable machine.....	42,018 lbs.
McColl's power riveter, light blow.....	69,384 lbs.
McColl's power riveter, heavy blow.....	115,640 lbs.

It was considered most likely that the pressure which is brought to bear on the rivet head whilst forming, must have a considerable influence on the quality of the rivet; hence these tests.

TABLE XXXIX.
RIVET TESTS.

All rivets of steel. Diameter of rivet steel, $\frac{5}{8}$ inch; diameter of hole, $\frac{1}{8}$ inch.
Section sheared, two circles of $\frac{1}{8}$ inch diameter, --- 0.7424 square inch.
Shearing strength of the original steel bar, 49,683 pounds per square inch, or 36,885 pounds for 0.7424 per square inch.
Tensile strength of steel, 64,579 pounds per square inch.
Each figure of the table represents the average result of three specimens.
Greig and Eyth.

METHOD OF MAKING THE RIVET.	I	II	III	IV	V
	STEAM.	HYD.	HYD.	POWER	POWER
	LBS.	LBS.	LBS.	LBS.	LBS.
Pressure on rivet head	82,380	86,360	42,018	69,384	115,640
Breaking strain of sample.....	42,717	39,491	37,811	37,341	39,424
Shearing strain of steel in sample.....	36,885	36,885	36,885	36,885	36,885
Frictional resistance of sample.....	5,832	2,606	926	456	2,539
Frictional resistance between two surfaces.....	2,916	1,303	463	228	1,269

In regard to results obtained, taking columns I, II and V of the above table into account, because columns III and IV refer to rivets closed under exceptionally low pressure, the average breaking strain of the samples riveted by

steam, hydraulic or power pressure amounted to 40,544 pounds, whilst the mere shearing resistance was 36,885 pounds. The average frictional resistance, therefore, is 3,659 pounds. Thus it appears that on an average the shearing resistance of a five-eighths steel rivet is made up of 91 per cent of direct resistance to shearing and 9 per cent of frictional resistance. This, of course, assumes that the direct shearing resistance is the same after the material has been made into a rivet, as before.

Steel rivets have been but little used and have never been in favor until quite recently. The same faults existed in rivets which were found in the earlier steel plates, viz: high tensile strength and low ductility; to this must also be added improper working in the boiler shop. From the results of recent practice there is reason to believe that mild steel possesses every requisite for a good rivet. The tensile strength should not be much above 58,000 pounds per square inch and should be tough enough to rivet cold. In using steel rivets in the boiler shop they should be uniformly heated throughout, and not the points merely, as is the ordinary method of heating iron rivets; neither should they be heated as highly as iron rivets and should never exceed a bright cherry red. Particular attention must be given to the thickness of the fire; steel, of whatever kind, should never be heated in a thin fire, especially in one having a force blast, such as an ordinary blacksmith or riveting fire. The reason for this is, that more air passes through the fire than that needed for combustion, and in consequence there is a considerable quantity of free oxygen in the fire which will oxidize the steel, or in other words, burn it. If excluded from this free oxygen steel can not be burned; if the temperature is high enough it can be melted and will run down through the fire, but burning is impossible in a thick fire with a moderate draft.

This is an important matter in using steel rivets and should not be overlooked; the same principle applies to the heating of steel plates for flanging.

Tables XL and XLI give the results of mechanical tests made on American rivet steel. The first table gives results by means of a Thurston torsional machine, the latter on one by Riehle Brothers.

TABLE XL.

TORSIONAL TESTS OF BESSEMER RIVET STEEL MADE BY THE EDGAR THOMPSON STEEL WORKS.

(Specimens five-eighths inch diameter, one inch long between shoulders).

	1	2	3
Angle of torsion.....	351°	423°	337°
Moment of torsion.....	281 ft.-lbs.	291 ft.-lbs.	298 ft.-lbs.
Tensile strength at elastic limit.....	35,998 lbs.	37,886 lbs.	37,883 lbs.
Ultimate tensile strength.....	56,913 lbs.	43,500 lbs.	56,004 lbs.
Per cent of elongation (torsional).....	116	150	109
Carbon in the specimens.....	0.11 per cent.	0.14 per cent.	0.15 per cent.

Samples of the 0.11 and 0.14 per cent rivet steel, turned to one-half inch diameter and three inches between shoulders, were tested by Mr. Borntraeger on a Riehle Brothers' testing machine, with results as below:

TABLE XLI.

TENSILE TESTS OF BESSEMER RIVET STEEL MADE BY THE EDGAR THOMPSON STEEL WORKS.

SAMPLES.	1	2
Carbon in samples.....	0.11 pr. ct.	0.14 pr. ct.
Length of samples.....	3 inches.	3 inches.
Diameter of samples.....	$\frac{1}{2}$ inch.	$\frac{1}{2}$ inch.
Area of sample.....	.1963 inch.	.1963 inch.

TABLE XLI—CONTINUED.

SAMPLES.	1	2
Elastic limit of sample.....	8,200 lbs.	7,500 lbs.
Elastic limit per square inch	41,772 lbs.	38,206 lbs.
Weight at which sample broke.....	12,500 lbs.	11,750 lbs.
Tensile strength per square inch.....	63,678 lbs.	59,850 lbs.
Elongation	$\frac{7}{8}$ in 3 inches.	$3\frac{1}{2}$ in 3 inches.
Elongation, per cent.....	29	28
Diameter of reduced section .....	.35 inch.	.33 inch.
Area of reduced section.....	.096 inch.	.086 inch.
Percentage of original area.....	49	43.6
Percentage of reduction.....	51	56.4

Single riveted lap joints—This is the simplest form of a riveted joint and is used almost exclusively in riveted seams in boiler shells when of forty inches or less in diameter. Some manufacturers begin double riveting at thirty-six inches, but this is the exception rather than the rule. The single riveted joint, though easily made, is at best but about one-half the tensile strength of the solid plate. Among the defects of construction may be mentioned the liability of tearing the plate through the line of rivet holes, as shown in figure 22. This is liable to occur in any case where the rivet holes are punched too close together, thus reducing the strength of the plate below the shearing strength of the rivets. This is a fault which one may be easily led into and is perhaps the commonest defect in boiler construction.

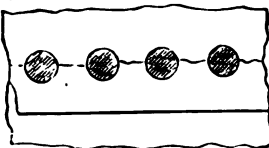


FIGURE 22.

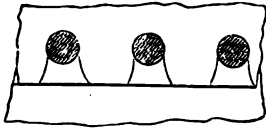


FIGURE 23.

Another cause of failure, though not nearly so common as the former, is that of punching the holes too near the edge of the plate. When the distance from the edge of the rivet is too near the edge of the

plate the latter is likely to give way in front of the rivet, as in figure 23. This defect is easily remedied by simply allowing a wider margin; and in consequence may be easily overdone, for if the edge of the plate be too far from the joint it makes calking the joint steam tight a much more difficult matter, owing to the spring or elasticity of the plate. On the other hand, if the rivet holes have their centers too far apart and the distance from the edge of the hole to the edge of the plate be such that the plate can not yield, as in figures 22 and 23, then there is a possibility of shearing off the rivets, as in figure 24. This is likely to occur when the rivets are too small in diameter for the thickness of the plate.

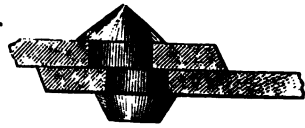


FIGURE 24.

The ultimate strength of a plate depends upon its area of cross section; and the loss of area caused by punching the holes for the insertion of the rivet, reduces the strength of the plate simply in that amount. With rivets, however, the case is quite dissimilar, for the strength of the rivet increases as the square of its diameter. In the former case the strength of the plate consists merely in that of the net area through the line of rivet holes; in the latter the resistance to shearing increases with the increased area of the rivet. Other things being equal, that is the best joint in which the strength of the plate and the resistance of the rivet to shearing are equal to each other. Hundreds of tests have been made to determine by direct experiment the best proportions for single riveted joints.

The differences in quality of boiler plate and rivets, together with the great uncertainty as to the exact effect of punching iron plates, have, so far, prevented anything like the determining either by calculation or experiment of what might be accepted as the exact, or better, perhaps, the best proportions for riveted joints. The writer has examined many formulas and finds that in most cases they are suited only to the one or two thicknesses of plates for which they were evidently intended, being usually three-eighths and seven-sixteenths inch, and have the appearance of having been worked out for the seams in Cornish or other large diameter internally fired boilers.

The thinner plates, one-fourth inch, for example, in English tables of proportions for riveted joints, give one-half inch as the proper diameter of rivets. This is not in accordance with American practice; five-eighths inch rivets in one-fourth inch plates being almost universal. The spacing of rivets is also greater in this country than in England.

The following tables were compiled by the writer for his own use, partly from theoretical deductions, partly from tests made on riveted joints, and also by a comparison of these with the practice of successful and intelligent manufacturers. It will be observed that the dimensions are empirical, yet they have served a good purpose and on the whole are quite reliable. This matter of spacing rivets is, at best, approximate only, and may be changed within narrow limits; it often happens that spacing will not come out even, and in such cases, whether the centers shall be increased or decreased, rests entirely upon the judgment of the designer. In general, it has been the practice of the writer to use the proportions in the table, and when spaces occur at the end to put in the extra rivet instead of throwing it out.

TABLE XLII.
SHOWING DIAMETER AND SPACING OF RIVETS IN SINGLE RIVETED
LAP JOINTS.

THICKNESS OF PLATE.	DIAMETER OF RIVET.	LENGTH OF RIVET.	CENTER OF RIVET TO EDGE OF PLATE.	CENTER TO CENTER OF RIVETS.
$\frac{3}{16}$ inch.	$\frac{1}{2}$	1	$1\frac{3}{8}$	$1\frac{1}{2}$
$\frac{1}{4}$ inch.	$\frac{5}{8}$	$1\frac{1}{4}$	1	$1\frac{3}{4}$
$\frac{5}{16}$ inch.	$\frac{5}{8}$	$1\frac{1}{2}$	1	$1\frac{1}{4}$
$\frac{3}{8}$ inch.	$\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{16}$	2
$\frac{7}{16}$ inch.	$\frac{3}{4}$	2	$1\frac{3}{16}$	$2\frac{1}{2}$
$\frac{1}{2}$ inch.	$\frac{7}{8}$	$2\frac{1}{4}$	$1\frac{3}{8}$	$2\frac{3}{8}$
$\frac{9}{16}$ inch.	$\frac{7}{8}$	$2\frac{1}{2}$	$1\frac{3}{8}$	$2\frac{1}{2}$
$\frac{5}{8}$ inch.	1	$2\frac{3}{4}$	$1\frac{9}{16}$	$2\frac{5}{8}$
$\frac{11}{16}$ inch.	1	3	$1\frac{9}{16}$	$2\frac{1}{2}$
$\frac{3}{4}$ inch.	$1\frac{1}{8}$	$3\frac{1}{4}$	$1\frac{7}{8}$	3

Double riveting—Boilers ought to be double riveted, if for no other reason, simply as a matter of economy, for the strength of the single riveted joint, which is only about one-half the strength of the solid plate, is increased by about twenty per cent by double riveting, without any such corresponding increase in cost.

The strength of a joint depends largely upon the strength of the rivets, and these must be so disposed in the joint as to utilize the strength of a larger number than can be used in single riveting, and at the same time increase the net sectional area of the plate in the line of punched holes in the joint. The writer does not think it a good plan to change the diameters of rivets in fixing upon single or double riveted joints. The two tables therefore contain the same diameters of rivets for the same thickness of plates.

TABLE XLIII.
FIXING DIAMETER AND SPACING OF BIVETS IN DOUBLE RIVETED LAP JOINTS.

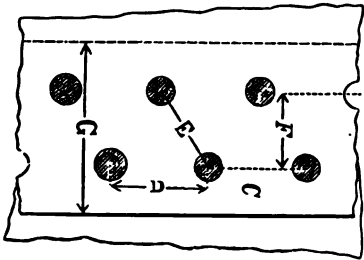


FIGURE 25.

THICKNESS OF PLATE.	RIVETS.		CENTER TO EDGE OF PLATE.	CENTER TO CENTER.	CENTER TO CENTER.	CENTER TO CENTER.
	DIAMETER	LENGTH.				
A	B	b	C	D	E	F
$\frac{1}{4}$	$\frac{3}{8}$	$1\frac{1}{4}$	1	2	$1\frac{7}{8}$	$1\frac{9}{16}$
$\frac{5}{16}$	$\frac{5}{8}$	$1\frac{1}{2}$	1	$2\frac{1}{4}$	2	$1\frac{11}{16}$
$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{16}$	$2\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{13}{16}$
$\frac{7}{16}$	$\frac{3}{4}$	2	$1\frac{3}{8}$	$2\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{3}{4}$
$\frac{1}{2}$	$\frac{7}{8}$	$2\frac{1}{4}$	$1\frac{3}{8}$	3	$2\frac{7}{16}$	$1\frac{13}{16}$
$\frac{9}{16}$	$\frac{7}{8}$	$2\frac{1}{2}$	$1\frac{3}{8}$	$3\frac{1}{4}$	$2\frac{9}{16}$	2
$\frac{5}{8}$	1	$2\frac{3}{4}$	$1\frac{9}{16}$	$3\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{1}{8}$
$1\frac{1}{8}$	1	3	$1\frac{9}{16}$	$3\frac{3}{4}$	$2\frac{7}{8}$	$2\frac{3}{16}$
$\frac{3}{4}$	$1\frac{1}{8}$	$3\frac{1}{4}$	$1\frac{3}{4}$	4	3	$2\frac{1}{4}$

The distance F is approximate only, column E being the exact distance.

Calking—In boiler making calking is a process of setting the overlapping edges of plates by means of a tool called a calking chisel. A full size representation of a calking end is given in figure 25 and marked “old

style calking." When two rough boiler plates are riveted together they are not steam tight; the object of calking is to "upset" the edge of the overlapping plate and drive it firmly down upon the one underneath. This operation does not, of course, alter the character of the joint; it simply forces the edge of the outside plate down firmly upon the lower one and thus a joint at first approximately tight is rendered altogether so by this simple operation.

The edges of plates ought always to be planed or sheared to the proper bevel for calking before riveting together. The angle of plates best suited for calking is about 20° less than a right angle. The practice of chipping seams after riveting is altogether wrong, as it endangers the strength of the plate underneath by the frequent and inevitable markings caused by the slipping of the chisel in the hands of the chipper. The markings are ruinous to the plates containing them, and are, no doubt, a frequent cause of disaster. Aside from the injury done the plates by careless chipping, the operation of calking by means of a sharp edge, even though it approximate a right angle, is also destructive to the lower plate, by forming a slight indentation the whole length of the seam so operated upon. An improved form of calking, patented by Mr. James W. Connery, Philadelphia, Pa., is shown in figure 26, and named by him "concave" calking, after the appearance of the finished joint.

The object of concave calking is to bring together the seams of a boiler after riveting, in such a manner that they shall be perfectly steam tight and at the same time not in any manner injure the under sheet. This is effectually accomplished by the use of a tool with a semi-cylindrical end, producing a concave depression in the bevelled edge of the lap; slightly dividing the plate calked and driving the divided part towards the rivets, forming a bearing from one-half to three-quarters of an inch, thereby forming a

proper junction of the two surfaces and increasing the strength of the joint, without in any manner injuring the surface of the under plate.

The accompanying cut illustrates the difference between the old and the new systems.

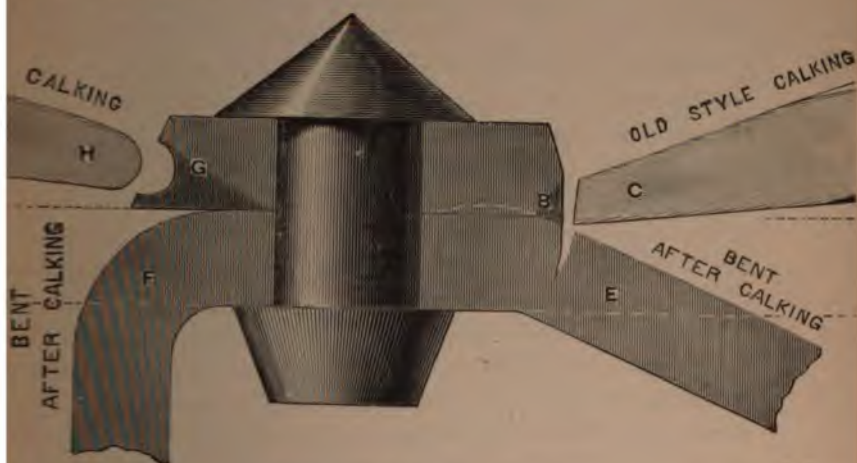


FIGURE 26. FULL SIZE.

The old plan is to chip or plane the edge of the overlapping sheet, leaving a solid angle to it of about 80° , and then to drive up, by means of a hammer upon the tool shown at the right, the under face of the tool resting upon the under sheet, until the angle of the metal of the upper sheet has assumed something near the form there shown. With a tool of this form it is impossible to thoroughly upset or calk the metal of the upper plate without a more or less injury or scoring of the under plate; and this will not be the only injury done the under sheet, for it is well known that in all processes of hammering, rolling and otherwise compressing iron, it becomes harder and more dense, and as there is nothing in the process of calking with this tool which makes any change in the material of

the under plate, it follows that after indentations and channelings are made in the under plate by the calking tool, the extreme edge of the upper plate, while being hardened and compressed; will be imbedded in the under plate, thus aggravating the injury done with the tool. These effects are plainly shown in plates which are cut apart after the most careful calking, and is well illustrated in the figure as giving to the plate that starting point of fracture with which all mechanics in metal are familiar. With Connery's improvement a concave depression is produced in the bevelled edge of the lap, the crown of the tool being entered in the edge of the plate at such a distance from the under plate as will leave, when finished, a considerable thickness of metal between the concave groove and the lower plate; the surface of the compressed and hardened metal, driven down upon the lower plate, will be too large to cause any appreciable disturbance of the surface of the under plate, while the tool can, under no circumstance, injure or mar the lower plate in any way.

It will be readily seen, too, that this form of tool, commencing as it does on a small surface for indentation of the edge, must result in carrying the compression or condensation of the iron of the lap to a much greater depth than is possible with the old method, thus tending to bring about a permanent strain upon the iron through the line of rivets in a much less degree. This is indicated on the left of the cut by the deep wedge of dark shading running nearly into the rivets.

Many of our first class establishments have adopted this method of calking, among which is the Baldwin Locomotive Works of Philadelphia, who have been using this improvement exclusively for several years upon their hundreds of locomotives and indorse it in the highest degree.

The writer is so fully impressed with the value of this invention that he does not hesitate to recommend it in all

cases as being superior to any other method of calking of which he has any knowledge; such a thing as grooving or injuring the lower plate by calking being practically impossible, and which gives this invention its chief value.

The following tests were made at the Washington Navy Yard: "Five plates of different thicknesses were riveted together and the four seams on one side were calked by the Connery process, and those on the opposite side (by different boiler makers employed in the yard) by the ordinary process. Upon cutting the sheets apart, in every case, it was found that the bearing surfaces of the sheets were about double that of the seams calked by the ordinary method, and that there was no injury done to the under sheets, whereas the under sheets of the seams calked in the ordinary way were slightly indented in some cases, and in others were channeled or grooved about one-thirty-second of an inch in depth, depending upon the skill and care of the workmen employed. Several seams were also calked by the above process on an experimental cylinder which was subsequently tested to its collapsing pressure of one hundred and thirty-four pounds per square inch, without the slightest leak, whereas a number of leaks made their appearance in seams calked by the ordinary process."

Locomotive boilers tested by hydraulic pressure to more than three hundred pounds per square inch, and afterwards used with a steam pressure of one hundred and fifty pounds, showed no leakage at seams with this calking.

No joints in a boiler are more difficult to get tight than those which are single riveted. This is due to a partial distortion of the joint, caused by the shell of the boiler assuming a more perfect cylindrical form when pressure is applied than that given it in the boiler shop during the process of manufacture.

Figure 27 shows, by means of the dotted lines, the curved surface of the cylindric part of the shell, and the

full lines the actual position of the joint; and it is just here that the mischievous effects of the grooving caused

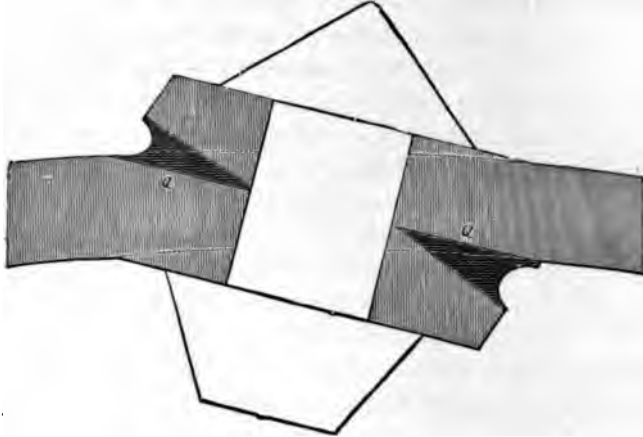



FIGURE 27. FULL SIZE.

by chipping and sharp calking become fully apparent, and which is shown in an exaggerated degree in figure 26, by the breaking of the plate.



CHAPTER VII.

WELDING, FLANGING AND INFLUENCE OF TEMPERATURE.

Welding Boiler Plates—Advantages Claimed—Objections to Welding Externally Fired Boiler Shells—Practical Difficulties in Welding Long Seams—Strength of Welded Joints—Welded Rings for Boilers—Flanging—Influence of Temperature on Boiler Plates—Mr. Isherwood on the Franklin Institute Experiments of 1837.

Welding boiler plate joints—Very little attention has been given in this country to the production of welded boiler plate joints. The few experiments that have been made have been so crudely done that no intelligent opinion can be formed as to the relative costs of welded and riveted work. In England welded joints have been in use for several years and for some purposes is steadily growing in favor, though it is not practiced in boiler construction to any great extent as yet.

The advantages claimed for this form of joint over the ordinary riveted joint are,

1. That the welding approximates more ~~clearly~~ the original strength of the plates than the best forms of riveted joints can possibly do, besides being entirely free from the bad effects of punching and loss of strength occasioned by drifting, as well as the injury done the plates by cold hammering.

2. The welded joint needs no calking, and thus, next to drifting, one of the greatest evils through bad workmanship in boiler construction is rid of entirely.

3. By welding the rings in the shell of a boiler they may be re-rolled after the work is done on them, and thus

a perfectly cylindrical shell can be produced, a thing impossible in the ordinary lap joints.

If an entire shell could be welded, it would remove at once the objectionable two thicknesses of plate in the fire and the trouble incident to the accumulation of deposit which is likely to form around the joints and rivet heads; and, further, there being no jointed seam, entirely precludes such a thing as corrosion caused by leakage at the lap of the plates or around loose or imperfectly fitted rivets.

Whether a welded joint is to be preferred over a riveted one, will depend upon circumstances. In an internally fired boiler it is important that the main flue should be truly cylindrical, as the resistance to collapse depends largely upon this. The best makers usually employ in its construction a butt riveted joint with the seam underneath. The objections to this are, that it is impossible to perfectly calk such a seam when once in place; and then the seam of rivets along the bottom of the flue will prevent the ready removal of ashes and dust which accumulates along its whole length. Should there be a leaky joint, a thing we may almost certainly count on, there will in time be quite an accumulation of hard baked ashes and cinders the whole length of the flue. In case the fuel used contained sulphur, there would be more or less of sulphurous oxide mixed up with the ashes or deposited along the sides or bottom of the boiler flue, and which, if once wet or dampened, will attack the flue by external corrosion and seriously impair its strength. In such a case a welded and perfectly tight flue would possess a marked advantage over the other, to say nothing of that gained by the truly cylindrical form; this advantage, it should be understood, refers to the facility and certainty in cleaning and freedom from leaks, and not that the corrosive action would be less under the same conditions.

In such a flue, as just described, the pressure tends to collapse and thus to tighten the weld. An imperfect weld might, in such a flue, escape detection for a long time, but which would soon make itself apparent in any case where internal pressures were employed.

In externally fired boilers, the main advantage of welded seams over riveted ones appear to be the getting rid of all the double thicknesses of plates in the fire. This is at all times a desirable thing to do. In boilers of this type, the strains are from within, outward, and the safety of the shell depends entirely upon the tensile strength and ductility of the plates and the soundness of the weld. The strength of a riveted joint is known to within a very small percentage of the weight required to tear it apart. For welded joints, unfortunately, no such exact data exists, and from the nature of the joint it is exceedingly difficult to arrive at anything even approximating its actual strength; not that experimental tests are wanting, nor that sufficient time has been denied the subject in order to make the fullest investigation in regard to the effect upon the plates joined by welding, the weld itself, or the proper mechanical manipulation of the plates in the fire. We have all this, and it only goes to show what the possibilities are, but gives no data as to probabilities in actual practice, on a large scale, with even good facilities and skilled workmen.

The welding of two plates in a well made open fire is attended with greater risks than the welding of two bars of iron. The reasons for this are quite obvious. In the case of the bars, their ends are in the center of the fire and entirely shut off from the injurious effects of free oxygen, if the fire is properly made. When a thick fire is built upon the tweer, the air passing up through it gives up its oxygen to the highly heated carbon, and carbonic acid gas is formed as the result of this union, and in passing up still further through this bed of burning coal, the carbon in the

upper portion of the fire may take up a portion of the oxygen in the carbonic acid gas, and carbonic oxide gas is formed. Neither of these gases has an injurious effect upon iron so far as welding is concerned, and in the case of the two bars referred to above, they are in this highly heated chamber of gases formed by the sides and cover of the fire, and may be readily brought to a welding heat without any fear of oxidation, for there is no excess of oxygen in the fire to come in contact with the iron.

In the case of the plates it is somewhat different, for the fire being hottest in the center and of lower temperature toward the edges, it is not possible to confine the plates to a chamber of heated gases from which oxygen is excluded, for no such chamber exists, and can not, from the nature of the case. Further, every movement of the plates brings the more or less highly heated portions in contact with the air, when oxidation instantly occurs, forming an oxide of iron or hard cinder which prevents welding. There is at the same time a partial loss of iron, but this is not of so much account as the bad effects resulting from the presence of the cinder in the weld.

It is not practicable to heat any considerable length of plate in an ordinary forge or flanging fire at one time, and as the oxidation referred to is sure to occur in a greater or less degree, the surfaces must be protected from oxidation by means of a flux. The one generally used is sand; this is composed of silicon and oxygen. The action of the flux may be said to be two-fold: first, in forming a vitreous coating over the iron, and second, in reducing the temperature of the parts to which it is applied, and arises from the circumstance that iron is usually "scarfed" at the place where it is to be welded; we thus have a thick and a thinner portion of the same plate exposed to the action of the heat, the thinner portion of the plate being nearest the center of the fire, and arrives at a welding heat long before

the thicker portion of the plate attains a similar heat. If the action of the heat was not checked, this thinner edge would be burned away long before the plate was brought to the welding point. In order to prevent this the sand or other flux is used, and in coming in contact with the highly heated iron it is melted and absorbs so much heat from the iron that it gives the latter a vitreous coating. This silicate combines with the iron and covers that portion of it which is of sufficiently high temperature to melt the sand. This silicate being of a very refractory nature, will last some time in the fire before it burns off the iron, and in this manner serves to protect the thinner parts of the iron, while the thicker portion is absorbing the heat and arriving at a welding condition.

In using sand as a flux, care must be exercised that it be kept, or afterward cleaned off, the inside of the joint where the two scarfed edges of the plate are to be welded, as its presence in the weld prevents perfect contact, and thus weakens the joint. For small work, borax is the flux generally employed in the forge for welding. It prevents oxidation in the same manner as already described for sand.

There are many ways of making a welded joint and they will vary anywhere from good to bad in strength and soundness. Scarf welding is on the whole to be preferred to simply lapping the plates and then welding. In scarfing, the edges of the plates should be upset and then thinned down, not exactly to a sharp edge, but say one-sixteenth of an inch, or perhaps less. The exact thickness is of course no material part of the process of making a good joint; neither is the thinning of so much importance as the upsetting of the edge of the plate to a thickness greater than that of the plate itself, the object being that when the weld is made it may then be finished down with suitable "flatters" to the regular thickness.

In the manufacture of welded boilers as a business, it would be necessary to construct a special heating apparatus, which would probably consist of an external and an internal gas furnace, operating on the principle of the blow pipe, in which the flame of the burning gas would be directed against such portions of the joint as needed the greater heat. Such an apparatus could be made in which no free oxygen could reach the heated plates, and thus welds could be made without the use of a flux of any kind. The plates could be heated the whole length at one time and when brought to the proper heat could be welded by pressure instead of by hammering.

What the future may bring forth, it is impossible even to conjecture, but at present welded boiler plate joints, especially when intended for externally fired boilers, are untrustworthy and are almost sure to contain imperfections in the weld which the usual hydraulic test fails to indicate, but which will reveal themselves sooner or later in the expansion and contraction incident to heating and cooling in actual service.

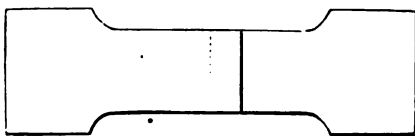


FIGURE 28.

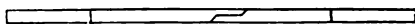


FIGURE 29.

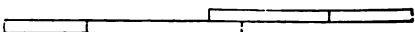


FIGURE 30.

In Mr. Bertram's experiments on welded joints the lap welded test pieces, figure 30, were inferior in strength to those scarf welded, figure 29.

The specimens tested were four inches wide by three-eighths, seven-sixteenths and one-half inch in thickness. The lap of the joint was one and a quarter inches.

The results were as follows :

TABLE XLIV.

	$\frac{1}{2}$ INCH PLATE.	$\frac{7}{16}$ INCH PLATE.	$\frac{3}{8}$ INCH PLATE.
Strength of entire plate, per cent.....	100	100	100
Strength of scarf welded joint, fig. 29,	Faulty.	106	102
Strength of lap welded joint, fig. 30.	50	69	62

From the above data it appears that the strength of joints united by lap welding are scarcely better than single riveting, or about forty per cent weaker than the plates which compose the joint. Scarf welding, on the contrary, equaled the strength of the plate. No doubt the shape of the joint under severe stress had much to do with the lowering of its strength in consequence of the indirect pull.

In regard to the welding of steel boiler plates Mr. Daniel Adamson says:

"After many trials and many failures in attempting to weld steel boiler plates, the writer found it necessary to ascertain in all cases the composition of the metal before putting any labor on it, and from a large experience it is now considered desirable that the carbon should not exceed one-eighth of a per cent, while the sulphur and phosphorus should, if possible, be kept as low as .04 per cent, silicon being admissable up to the extent of $\frac{1}{16}$ of 1 per cent. Further experience is yet required to ascertain what exact composition gives the most satisfactory results by welding. At present some preference may be said to be given to the Martin-Siemens

class as compared with Bessemer metal, when both are of about the same chemical composition."

Weldless rings for boilers—Several years ago (1865?) Mr. Ramsbottom designed a machine to work annular ingots of Bessemer steel, or other metal, into cylinders of such length and thinness that they may be put between rollers and rolled round and round and reduced to the thinness required to make boilers. The machine consisted of a mandrel, on which the hoop or annular ingot was placed. On each side of the mandrel was placed a roller, the surfaces of the roller and mandrel being grooved diagonally in opposite directions, thus leaving diamond shaped projections on them. The rollers were intended to be driven by steam or other power, and were pressed against the hoop or ingot, which is enlarged in diameter and expanded lengthwise by the pressure and the lateral action of the projections on the rollers and mandrel. When the hoop or ingot has been thus partially expanded it was then to be put on another mandrel of larger diameter and again acted upon by the rollers; or it might be put on a revolving mandrel and thus expanded both in length and diameter by a roller which is traversed to and fro in the direction of the axis of the hoop. In this arrangement the hoop and traversing roller must be pressed together.

It has also been proposed and in a measure carried out, to forge the annular ingots by means of a steam or power hammer into the cylindrical sections of a boiler ready to rivet into a continuous shell.

From the present outlook it does not appear that either of these methods are likely to supersede the making up of flat sheets into shells and large flues, because of the increased cost of manufacture of the cylindrical weldless hoops over that of flat iron rolled, and then riveted or welded.

Flanging—The exterior flanging of a boiler head and small flue holes is about as severe a test as plate iron generally receives in the process of boiler construction. By far the greater number of heads used in this country are hand flanged; there are very few boiler making establishments having enough flanging to do to warrant the erection of suitable furnaces and machines. The few machines which are in use, however, attest the superiority of machine over hand flanging. In the first place the heads are perfectly round, an important matter of detail in boiler construction; in the next place the flange is turned perfectly true and at right angles to the face of the head. In hand flanging it is almost impossible to secure either or both of these in the same plate. The heating is done in the ordinary forge fire and liable to all the objections of overheating one portion of the plate while other portions are not of sufficiently high temperature to insure the best working.

In flanging an iron or steel plate, it should be done with wooden mauls, bending the plate over a cast iron former. The blows should be light and distributed over as large a surface as possible, avoiding anything like short bends in turning the flange. The heating, when done in an ordinary flange fire, must of necessity be local, and, hence, will require the greater care in working. As the flanging approaches completion by successive stages of heating and hammering, care must be exercised that the plate, if of steel, is not ruined by cracking or splitting, which may be induced by internal strains. To avoid this in subsequent working or handling, it should be immediately annealed by heating the whole plate gradually and evenly, until brought to a low red heat, and then allowing it to cool slowly, not disturbing it until entirely cold.

The writer has used a considerable number of heads, machine flanged, by Phillips, Nimick & Co., and aside from

the superior quality of "Sligo" iron, these heads seem to possess an advantage over the best hand flanged work by the strengthening of the plate in the curve, as shown in the annexed engravings.

Figure 31 represents the thinning of the curve occasioned by the stretching of the plate over the cast iron former in hand flanging, the dotted line representing the normal curve and the middle line the actual thickness of metal. Figure 32 is a representation of the thickening of the curve, taken from machine flanged heads, made on the machine used by the above named firm. The normal curve, it will be noticed, falls considerably within the actual line of the metal. The advantages gained by the strengthening of the head at that particular point are quite obvious, and are not likely to be underestimated.



FIG. 31.

FIG. 32

Figure 33 is an engraving made from a photograph taken from a boiler head, and is, all things considered, one of the best specimens of machine flanging the writer has yet seen. The dimensions of the head are as follows

Diameter outside, 72 inches.	Diameter large flue, 40 inches.
Diameter 2 holes, 12 inches.	Diameter 2 holes, 8 inches.
Diameter 6 holes, 6 inches.	Diameter 1 hole, 5 inches.

The influence of temperature on boiler plates—The influence of different temperatures on the strength of iron or steel is a question of great importance in engineering construction, and probably nowhere more so than in steam boilers. It is supposed that the effect of repeated changes in the temperature of iron plates brings about certain molecular changes, which destroys the cohesion of the iron in the same manner that it would be destroyed by the continued vibrations of a plate caused by any external force.

It is well known that the continued reheating and cooling of iron will shortly render it entirely worthless, if it approach a red heat. Plates cut out of that portion of old boilers subjected to the action of the fire are almost invariably hard and brittle, and will seldom show one-fourth of its original ductility, together with a marked decrease in tensile strength. This can be referred to no

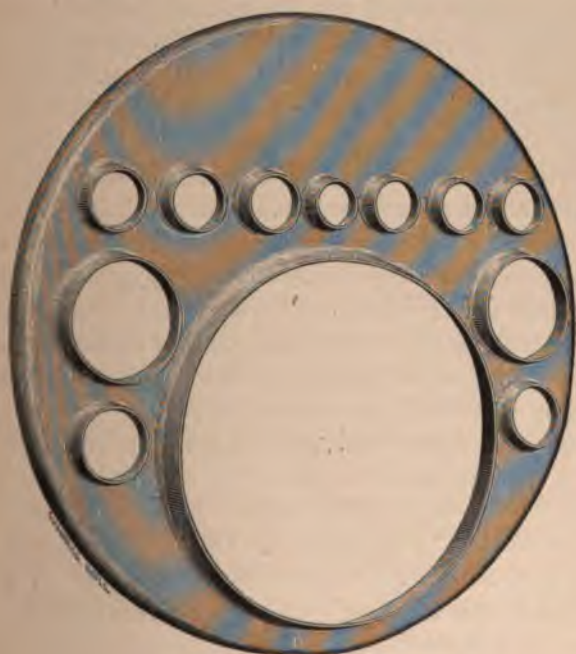


FIGURE 33.

other cause than that produced by molecular changes brought about by the long continued action of the fire.

Wrought iron is apt to blister or crack in overheating and changes its structure from fibrous to coarse granular, losing in tensile strength and ductility and becomes more

brittle. The loss in tensile strength in overheated iron plates has doubtless been a cause of many boiler explosions and can only be explained by the possibility that the continued variation and differences of temperature of the outer and inner surfaces of the plate have diminished the cohesion of the fibers or laminæ composing it. If this is true of fibrous iron, what would be the effect of the temperature on granular iron? Sir William Fairbairn ascertained, in his experiments, that on the whole cast iron of average quality loses strength when heated beyond a mean temperature of one hundred and twenty degrees, and that it becomes insecure at the freezing point or under thirty-two degrees Fahrenheit. Cast iron yields to the fire sooner than wrought iron; it loses a considerable percentage of strength at about two hundred degrees, and when red hot will scarcely sustain its own weight. The effect of variations of temperature on mild steel has not been so closely observed as that on wrought iron, and while we have any reason to believe that molecular changes are undergone in the material in consequence of repeated heating and cooling, it does not appear that the strength is diminished in any considerable amount when the plates are used in steam boilers. In case the boiler should become short of water, or in event of plates being overheated in such portions of the boiler as are not protected by the water, then the effect of excessive and continued overheating is to render the plates coarse granular, losing in tensile strength and toughness.

Wrought iron will the better withstand the effects of repeated heating and cooling in proportion as it is free from cinder; hence, a fine granular and homogeneous iron will resist the bad effects of reheating better and longer than a coarse fibrous iron, because the latter is made fibrous by containing in its composition more or less cinder, which, owing to the lower temperature of the finishing

heats, was prevented from escaping. As a result, it can never equal in strength and ductility the granular iron, and is apt, with even a moderate degree of overheating, to become extremely brittle; and it is for this reason that it should never be used for the fire sheets of boilers.

Heating to redness and slow cooling—or in other words, annealing—has an effect on steel in which it is rendered more ductile than before, but at a reduction of its tensile strength; such a plate once annealed does not apparently change by reheating, unless the temperature is higher than that to which it was first brought. By this it is not to be understood that no molecular changes are going on in the metal because of the lower temperature, but rather that the destructive changes in steel plates are less in degree than in iron plates if there is no sudden cooling. Steel plates, in order to anneal them properly, should be brought up to a temperature higher than that at which the final work was done on them. A cherry red will be found to be somewhat higher than the final working heat, and in boilers higher than any subsequent heat. Steel plates must not be annealed at too high a temperature; that is, the temperature must not be near the melting point, because it will change its texture and crystallize by slow cooling, thereby losing in tenacity, ductility and elasticity, rendering the plate worthless.

The operation of heating and sudden cooling produces effects directly the opposite of the above, and its subsequent behavior is not unlike that of similar pieces which have been brought to a strain exceeding the elastic limit; that is, the tensile strength is increased, as is also its brittleness. Any metal, therefore, which will harden in cooling is not fit to enter in boiler construction because of this very property of becoming brittle and thus reducing its power to endure sudden variations in load or resistance to shocks.

In regard to the accidental overheating of steel plates, caused by low water, there have been many instances of collapse or of bulging, but such a thing as fracture in connection with overheating is almost unknown.

Mr. Adamson observes that few or no malleable metals, such as wrought iron or mild steels, can be found in the open market that possess a range of endurance at all varying temperatures, say, from cold up to red heat, but nearly all ordinary bar or boiler iron and mild steels will endure considerable percussive force when cold and up to 450° Fahrenheit, after which, as the heat is increased, probably to near 700°, they are all more or less treacherous and liable to break up suddenly by percussive action. The poorer class of metals at this temperature, which may be called a color heat, varying from a light straw to a purple and dark blue, are simply rotten. Some of these peculiar properties are illustrated by a series of tests of various qualities of metal; for example: ordinary merchant iron shows that it may be bent cold, or it may be bent red hot without signs of breakage or much distress. Examples are not wanting to show that irons will endure this bending test when cold or when red hot, but such a heat as can be induced by placing the metal into a bath of boiling tallow, registering a temperature of about 610° Fahrenheit, these metals break through by being bent, lose most of their malleability and snap off short under the action of the hammer.

The same unfortunate element is exhibited by the mild class of Bessemer and Martin-Siemens steel, with this difference, that they bent better cold and more pleasantly when hot, but both break up by percussive action at the medium temperature before named, the Martin-Siemens enduring somewhat better than the Bessemer class under these tests.

During several years of observation Mr. Adamson has come to the conclusion that no metal containing much

above a trace of sulphur can endure bending at this color heat, while at the same time the phosphorus must be low; in fact, such endurance can only be obtained by a comparatively pure iron, unalloyed by any other ingredients.

Experiments made by Mr. Adamson, with bars of iron one inch in diameter and ten inches long between supports, when under tensile strain gave the following mechanical data:

Permanent set induced per square inch.....	36,287 pounds.
Maximum strain per square inch.....	53,476 pounds.
Elongation under maximum strain.....	18 per cent.
Final breaking strain on original area per square inch.....	50,929 pounds.
Per cent of elongation.....	20.5

A piece of this same iron subjected to chemical analysis yielded,

Iron.....	99.44
Carbon.....	trace
Manganese.....	0.10
Silicon.....	0.16
Sulphur.....	0.01
Phosphorus.....	0.29
	<hr/> 100.00

This iron was tested with a view to examine its power of endurance at a low heat, and at temperatures varying from 500° to 600° Fahrenheit it was found very difficult to get a bent piece; and by referring to the composition of this iron, it will be found to contain a large measure of phosphorus, which in some degree may explain its lack of power to resist percussive force at the heats just named; nevertheless, this cheap ordinary iron is much more valuable for many practical purposes than pure and comparatively expensive wrought irons.

Franklin Institute experiments—The influence of temperature on the strength of wrought iron boiler plates was

investigated in 1837 by a committee of the Franklin Institute and their conclusions were, that, the tenacity of boiler plates increased with the temperature up to five hundred and fifty degrees Fahrenheit, at which point the tenacity began to diminish. The tensile strength per square inch of section

At 32° Fahrenheit was.....	56,000 pounds.
At 570° Fahrenheit was.....	66,500 pounds.
At 720° Fahrenheit was.....	55,000 pounds.
At 1050° Fahrenheit was.....	32,000 pounds.
At 1240° Fahrenheit was.....	22,000 pounds.
At 1317° Fahrenheit was.....	9,000 pounds.

Mr. Isherwood, in a contribution to the Franklin Institute Journal in 1874, shows, in a very convincing manner, that the committee erred in judgment in continuing the experiments with the same specimens successively after rupture. He says:

“In the experiments the same piece of iron was successively ruptured and gave as a general result just what might have been expected, namely, increased tenacity at each rupture under ordinary atmospheric temperatures; but the committee failed to detect the reason and left the naked fact standing in their tables without explanation. The experiments made by the committee under high temperature were vitiated by the same cause, as they were made on the same piece of iron after it had been broken—often several times—under low temperatures. The committee did not perceive that the greater tenacity of the iron observed under the high temperature might be due to the fact that the iron was then necessarily fractured at a stronger point than under the preceding low temperatures; but they compared, in all cases, the tensile strength obtained from the first trial under low temperatures with the tensile strength under the high temperature often after several fractures had been made under the low temperature and the weakest points thereby eliminated.

"The tenacity thus found under the high temperature, was of course, as much too great, comparatively, as the tenacity under the low temperature, for the number of fractures made, exceeded the tenacity at the first fracture under the low temperature. Yet, obvious as is this deduction, the committee ignored it and attributed the entire increase of tenacity shown under the high temperature to the influence of that temperature alone, while, in fact, this increase was mainly, if not wholly, due to the elimination of the weakest points by the several previous fractures of the iron made under low temperatures.

"As far as I am aware, this fact of the necessarily increasing tenacity of the iron at successive fractures, as a consequence of the continued elimination of weaker points by each preceding fracture, is now pointed out by me for the first time. The failure to perceive it caused Professor Walter R. Johnson to attribute an actual increase of strength conferred on the iron by the simple process of stretching, whereas this result was solely due to the removal of weak points.

"Combining this error with that of the increase of strength assumed to be due to high temperatures, but really due to the same cause, led him to propose what he termed 'thermo-tension' treatment of iron as a means of increasing its tenacity. The whole principle of his process, however, being based on fallacious assumptions, its practical application proved worthless.

"From a careful comparison of all the experiments I have been able to collect concerning the influence of temperature on the tenacity of wrought iron, the results show that between the temperatures of zero and 550° Fahrenheit, this influence is exactly nil, developing the important fact that between these limits no provision need be made by the engineer for effect of difference of temperature."

CHAPTER VIII.

STRENGTH OF BOILERS.

Ultimate Strength—Factor of Safety—Safe Working Load—Strength of Riveted Shells—Collapsing Pressures—Strength of Welded Tubes—Stay Bolts and Braces—Steam Domes—Man Holes.

The strength of a boiler will depend upon the material of which it is made; the form and dimensions of its exterior and interior portions; the strength of intersecting joints, such as steam domes, nozzles, etc.; the strength of the riveted joints, and that of the system of stays which bind the portions of the whole together.

The ultimate strength of a boiler is seldom or never called in question, except in connection with its safe working pressure; the former being necessary, however, to the determining of the latter. The strength of iron and steel plates, both single and double riveted, have already been given, but it yet remains to fix upon the strength of riveted shells and flues in their actual form and dimensions before the working pressure can be set with safety. The ultimate strength of a boiler is the greatest pressure which it is capable of withstanding without danger of rupture. It is not necessary that the failure occur at the moment of over pressure, but whether it is likely to occur at all by a continued application. Experiments of this kind are both difficult and costly, and are therefore rarely made. Knowing the longitudinal and transverse strength of iron or steel plates, the strength of riveted joints, and in part, the many destructive influences which are at work and daily lessening the strength of the boiler, a certain frac-

tion of the ultimate strength, called a factor of safety, is selected as a basis of calculation at which boilers are considered safe, after taking into account all the contingencies incident to boiler making and subsequent use (and, shall I say abuse?) in regular service.

A factor of safety, in steam boilers, is a unit employed to show in what proportion a given pressure is less than the ultimate strength of the boiler. If a boiler is capable of withstanding an ultimate pressure of nine hundred pounds per square inch, and is used at a pressure of one hundred and fifty pounds, there is said to be a factor of safety of six with reference to the lower pressure, as compared with the ultimate strength. The numerical value given a factor of safety is the relation which it bears to the ultimate strength, and not that of the elastic limit; just what that figure should be for boilers has never been agreed upon, but has been narrowed down to either six or eight; so that in ordinary boiler construction for land use, no very great discrepancies are likely to occur by the use of either in the regular course of business. In this country six is the ordinary factor of safety employed in all kinds of boiler work; in England it varies between six and eight. It is the practice among the best class of boiler makers in this country to make no boilers less than one-quarter inch thick, no matter if the factor of safety should reach ten or even twenty. This practice results mainly from the difficulty in calking the seams in the plates.

TABLE XLV.

SHOWING THE TENSILE STRENGTH OF IRON AND STEEL PLATES, WITH SINGLE AND DOUBLE RIVETED JOINTS, AND THE SAFE WORKING STRENGTH PER SQUARE INCH OF SECTION, ALLOWING AS A FACTOR OF SAFETY ONE-SIXTH OF THE ULTIMATE STRENGTH.

STRENGTH OF SOLID PLATE IN POUNDS PER SQUARE INCH.	ULTIMATE STRENGTH OF RIVETED JOINTS.		SAFE WORKING LOAD OF RIVETED JOINTS PER SQUARE INCH.		
	SINGLE RIVETED AT 66 PER CENT.	DOUBLE RIVETED AT 70 PER CENT.	SINGLE RIVETED.	DOUBLE RIVETED.	SOLID PLATE.
45,000	25,200	31,500	4,200	5,250	7,500
50,000	28,000	35,000	4,667	5,833	8,333
55,000	30,800	38,500	5,133	6,417	9,167
60,000	33,600	42,000	5,600	7,000	10,000
65,000	36,400	45,500	6,067	7,583	10,833
70,000	39,200	49,000	6,533	8,167	11,667
75,000	42,000	52,500	7,000	8,750	12,500

The elastic limit of wrought iron is not far from one-half its tensile strength ; assuming it to be one-half, then the safe working load of solid plate as given in the above table has a factor of safety of only three as compared with the elastic limit. It is much easier to make tests for ultimate strength than for the limit of elasticity and the results are more definite ; it is for this reason, probably, more than any other, that the factor of safety is made referable to the ultimate, rather than the elastic strength of the material.

If we had nothing to deal with other than the pressure necessary to tear the boiler shell asunder in the line of rivet holes, or in the line of its least strength, the problem of strength in design would be a very simple one. Unfortunately this is not the case. Every one at all conversant with the details of boiler construction knows that

too many boilers are sent out with internal strains resulting from bad workmanship, which no doubt in some cases will equal the intended working pressure. The effect of these strains is to reduce the ultimate strength of the boiler and should always be taken into account. As there is no practical way of doing so we can only assume that a part of the factor of safety is already expended. But in what proportion? Perhaps no better answer can be given to this question than the data furnished in the following circular, issued by the English Board of Trade.

The strength of boilers—The following circular, issued by the English Board of Trade, is for the information of engine and boiler makers, to enable them to know under what instructions the inspectors of the board of trade act in recommending the pressure of steam to be carried in boilers within their jurisdiction:

“When boilers are made of the best material, with all the rivet holes drilled in place and all the seams fitted with double butt straps of at least five-eighths the thickness of the plates they cover, and all the seams at least double-riveted with rivets having an allowance of not more than fifty per cent over the single shear, and provided that the boilers have been open to inspection during the whole period of construction, then six may be used as the factor of safety. But the boilers must be tested by hydraulic pressure to twice the working pressure in the presence and to the satisfaction of the board's surveyors. But when the above conditions are not complied with, the conditions in the following scale must be added to the factor six, according to the circumstances of each case:

A	.15	To be added when all the holes are fair and good in the longitudinal seams, but drilled out of place after bending.
B	.3	To be added when all the holes are fair and good in the longitudinal seams, but drilled out of place before bending.
C	.3	To be added when all the holes are fair and good in the longitudinal seams, but punched after bending instead of drilled.
D	.5	To be added when all the holes are fair and good in the longitudinal seams, but punched before bending.
E*	.75	To be added when all the holes are not fair and good in the longitudinal seams.
F	.1	To be added if the holes are all fair and good in the circumferential seams, but drilled out of place after bending.
G	.15	To be added if the holes are fair and good in the circumferential seams, but drilled before bending.
H	.15	To be added if the holes are fair and good in the circumferential seams, but punched after bending.
I	.2	To be added if the holes are fair and good in the circumferential seams, but punched before bending.
J*	.2	To be added if the holes are not fair and good in the circumferential seams.
K	.2	To be added if double butt straps are not fitted to the longitudinal seams and the said seams are lap and double riveted.
L	.1	To be added if double butt straps are not fitted to the longitudinal seams and the said seams are lap and treble riveted.
M	.3	To be added if only single butt straps are fitted to the longitudinal seams and the said seams are double riveted.
N	.15	To be added if only single butt straps are fitted to the longitudinal seams and the said seams are treble riveted.
O	1.	To be added when any description of joint in the longitudinal seams is single riveted.
P	.1	To be added if the circumferential seams are fitted with single butt straps and are double riveted.
Q	.2	To be added if the circumferential seams are fitted with single butt straps and are single riveted.
R	.1	To be added if the circumferential seams are fitted with double butt straps and are single riveted.
S	.1	To be added if the circumferential seams are lap joints and are double riveted.
T	.2	To be added if the circumferential seams are lap joints and are single riveted.
U	.25	To be added when the circumferential seams are lap and the streaks or plates are not entirely under or over.
V	.3	To be added when the circumferential seams are not fitted with double butt straps and double riveted; when the boiler is of such a length as to fire from both ends, or is of unusual length, such as flue boilers.
W*	.4	To be added if the seams are not properly crossed.
X*	.4	To be added when the iron is in any way doubtful and the surveyor is not satisfied that it is of the best quality.
Y	1.65	To be added if the boiler is not open to inspection during the whole period of its construction.

Where marked * the allowances may be increased still further, if the workmanship or material is very doubtful or very unsatisfactory.

The strength of the joints is found by the following method:

$$\frac{(\text{Pitch} - \text{diameter of rivets}) \times 100}{\text{Pitch}} = \left\{ \begin{array}{l} \text{Percentage of strength of plate at} \\ \text{joint as compared with the solid} \\ \text{plate.} \end{array} \right.$$

$$\frac{(\text{Area of rivets} \times \text{No. of rows of rivets}) \times 100}{\text{Pitch} \times \text{thickness of plate.}} = \left\{ \begin{array}{l} \text{Percentage of strength of} \\ \text{rivets, as compared with} \\ \text{the solid plate.}^* \end{array} \right.$$

"Then take iron as equal to twenty-three tons, and use the smallest of the two percentages as the strength of the joint, and adopt the factor of safety as found from the scale given in this circular:

$$\frac{(51,520 \times \text{percentage of strength of joint}) \times \text{twice the thickness of the plate in inches.}}{\text{Inside diameter of the boiler in inches} \times \text{factor of safety.}} = \left\{ \begin{array}{l} \text{Pressure to be allowed} \\ \text{per square inch on} \\ \text{the safety valves.} \end{array} \right.$$

"Plates that are drilled in place must be taken apart and the burr taken off, and the holes slightly countersunk from the outsides. Butt straps must be cut from plates (and not from bars) and must be of as good a quality as the shell plates, and for the longitudinal seams must be cut across the fiber. The rivet holes may be punched or drilled out of place, but when drilled in place must be taken apart and the burr taken off and slightly countersunk from the outside. When single butt straps are used and the rivet holes in them punched, they must be one-eighth thicker than the plates they cover. The diameter of the rivets must not be less than the thickness of the plates of which the shell is made, but it will be found when the plates are thin, or when lap joints or single butt straps are adopted, that the diameter of the rivets should be in excess of the thickness of the plates—THOMAS GRAY."

Strength of riveted shells—The bursting pressure of a cylinder of either wrought iron or steel may be estimated as follows: Multiply together the tensile strength of the

* If the rivets are exposed to double shear, multiply the percentage as found by 1.5

material in pounds per square inch and its thickness; divide this by the radius of the shell in inches, which will give the bursting pressure in pounds per square inch. By this rule a cylinder forty-eight inches diameter, one-quarter inch thick, of iron having a tensile strength of forty-five thousand pounds per square inch would yield, at a pressure of 468.75 pounds, as follows: $\frac{45000 \times .25}{24} = 468.75$.

This is true only of a continuous shell without any joint; as it is not practicable to construct such a boiler with our present appliances a deduction must be made for the seam of rivets. If single riveted the strength would be reduced to, say, fifty-six per cent of the above, which would lower the pressure to 262.5 pounds; or if double riveted, to seventy per cent, which would fix the bursting pressure at 328. pounds. The safe working pressure, allowing a factor of safety of six, would be $\frac{468.75}{6} = 78.12$ pounds per square inch.

It will be observed that the factor of safety does not take into account whether the shell is single or double riveted. As there is approximately twenty per cent difference between the net results of the two percentages it is too large to be overlooked. It is customary to double rivet all longitudinal seams in boilers over forty-four inches in diameter, but not the circumferential seams. The stress on the end of a boiler is the area of the head multiplied into the pressure, and for the same shell as above would be, $48 \times 48 \times .7854 = 1809.6$ square inches area. The sectional area of the metal in the shell $= 48 \times 3.1416 \times .25 = 37.7$ square inches; this at 45,000 pounds per square inch would be capable of sustaining a load of 1,696,500 pounds before rupture; or dividing this by the area thus, $\frac{1696500}{1809.6} = 937.5$ pounds necessary to produce transverse rupture, or twice that of the longitudinal seams. If the same reduction be made for riveted joints as in the preceding example then $937.5 \times .56 = 525$ pounds as the ultimate

strength to resist rupture, as against 262.5 pounds for a single riveted, or 328 pounds for double riveted longitudinal seams, which goes to show that nothing is to be gained by double riveting circumferential seams in ordinary cylindrical shells.

If tubes or flues are inserted in the heads, their combined areas are to be deducted from the area of the head; this has the effect in many cases to reduce the pressure on the boiler heads more than one-half.

The following tables, XLVI and XLVII, show the safe working pressure per square inch for iron or steel boilers, either single or double riveted:

TABLE XLVI.

SHOWING THE SAFE WORKING PRESSURE FOR SINGLE RIVETED IRON CYLINDER BOILERS, FROM TWENTY-FOUR TO SEVENTY-TWO INCHES IN DIAMETER, EMPLOYING A FACTOR OF SAFETY OF SIX.

Single Riveted Iron Shells.

DIAMETER OF BOILER.	THICKNESS OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		40,000	45,000	50,000	55,000
24	$\frac{5}{16}$ inch.	PRESSURE. 104	PRESSURE. 117	PRESSURE. 130	PRESSURE. 143
	$\frac{1}{4}$ inch.	139	156	174	191
	$\frac{5}{16}$ inch.	174	195	217	239
26	$\frac{5}{16}$ inch.	96	108	120	132
	$\frac{1}{4}$ inch.	128	144	160	176
	$\frac{5}{16}$ inch.	160	180	200	220
28	$\frac{5}{16}$ inch.	89	100	112	123
	$\frac{1}{4}$ inch.	119	134	149	164
	$\frac{5}{16}$ inch.	149	167	186	205
30	$\frac{3}{16}$ inch.	83	94	104	115
	$\frac{1}{4}$ inch.	111	125	139	153
	$\frac{5}{16}$ inch.	139	156	174	191

TABLE XLVI—CONTINUED.

DIAMETER OF BOILER.	THICKNESS OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		40,000	45,000	50,000	55,000
		PRESSURE.	PRESSURE.	PRESSURE.	PRESSURE.
32	$\frac{3}{16}$ inch.	78	88	98	107
	$\frac{1}{4}$ inch.	91	102	114	125
	$\frac{5}{16}$ inch.	130	146	163	179
34	$\frac{3}{16}$ inch.	74	83	92	101
	$\frac{1}{4}$ inch.	98	110	123	135
	$\frac{5}{16}$ inch.	123	138	153	169
36	$\frac{3}{16}$ inch.	69	78	87	96
	$\frac{1}{4}$ inch.	92	104	116	127
	$\frac{5}{16}$ inch.	116	130	145	159
38	$\frac{3}{16}$ inch.	66	74	82	90
	$\frac{1}{4}$ inch.	88	99	110	121
	$\frac{5}{16}$ inch.	110	123	137	151
40	$\frac{3}{16}$ inch.	63	70	78	86
	$\frac{1}{4}$ inch.	83	94	104	115
	$\frac{5}{16}$ inch.	104	117	130	143
42	$\frac{3}{16}$ inch.	60	67	74	82
	$\frac{1}{4}$ inch.	79	89	99	109
	$\frac{5}{16}$ inch.	99	112	124	136
44	$\frac{3}{16}$ inch.	57	64	71	78
	$\frac{1}{4}$ inch.	76	85	95	104
	$\frac{5}{16}$ inch.	95	107	118	130
46	$\frac{3}{16}$ inch.	54	61	68	75
	$\frac{1}{4}$ inch.	72	82	91	100
	$\frac{5}{16}$ inch.	91	102	113	125
48	$\frac{3}{16}$ inch.	52	59	65	72
	$\frac{1}{4}$ inch.	70	78	87	96

TABLE XLVI—CONTINUED.

DIAMETER OF BOILER	THICKNESS OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		40,000	45,000	50,000	55,000
		PRESSURE.	PRESSURE.	PRESSURE.	PRESSURE.
48	$\frac{1}{16}$ inch.	87	98	109	120
50	$\frac{1}{8}$ inch.	67	75	83	92
	$\frac{1}{16}$ inch.	83	94	104	115
	$\frac{3}{8}$ inch.	100	112	125	138
52	$\frac{1}{8}$ inch.	64	72	80	88
	$\frac{1}{16}$ inch.	80	90	100	110
	$\frac{3}{8}$ inch.	96	108	120	132
54	$\frac{1}{8}$ inch.	62	69	77	85
	$\frac{1}{16}$ inch.	77	87	96	106
	$\frac{3}{8}$ inch.	93	104	116	127
56	$\frac{1}{8}$ inch.	60	67	75	82
	$\frac{1}{16}$ inch.	75	84	93	102
	$\frac{3}{8}$ inch.	89	100	112	123
58	$\frac{1}{8}$ inch.	57	65	72	79
	$\frac{1}{16}$ inch.	72	81	90	99
	$\frac{3}{8}$ inch.	86	97	108	119
60	$\frac{1}{8}$ inch.	56	63	70	77
	$\frac{1}{16}$ inch.	70	78	87	95
	$\frac{3}{8}$ inch.	83	94	104	115
66	$\frac{1}{8}$ inch.	51	57	63	69
	$\frac{1}{16}$ inch.	63	71	79	87
	$\frac{3}{8}$ inch.	76	85	95	104
72	$\frac{1}{8}$ inch.	46	52	58	64
	$\frac{1}{16}$ inch.	58	65	72	80
	$\frac{3}{8}$ inch.	69	78	87	96

The pressure given in the above and in the next tables for plates of 45,000 and 50,000 pounds tensile strength, agree closely with the best practice in this country for diameters ranging from thirty-six to forty-eight inches. Although single riveted seams may be strong enough for any pressure that may be required in any particular case, yet double riveting is to be recommended always, because the strength is increased thereby some twenty per cent; even then, it is thirty per cent below the strength of the solid plate.

TABLE XLVII.

SHOWING THE SAFE WORKING PRESSURE FOR DOUBLE RIVETED IRON CYLINDER BOILERS, FROM TWENTY-FOUR TO SEVENTY-TWO INCHES DIAMETER, EMPLOYING A FACTOR OF SAFETY OF SIX AND ADVANCING THE PRODUCT TWENTY PER CENT FOR DOUBLE RIVETING.

Double Riveted Iron Shells.

DIAMETER OF BOILER.	THICKNESS OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		40,000	45,000	50,000	55,000
		PRESSURE.	PRESSURE.	PRESSURE.	PRESSURE.
24	$\frac{3}{16}$ inch.	125	140	156	172
	$\frac{1}{4}$ inch.	167	187	209	229
	$\frac{5}{16}$ inch.	209	234	260	287
26	$\frac{3}{16}$ inch.	115	130	144	158
	$\frac{1}{4}$ inch.	155	173	192	211
	$\frac{5}{16}$ inch.	192	216	240	264
28	$\frac{3}{16}$ inch.	107	120	134	148
	$\frac{1}{4}$ inch.	143	161	179	197
	$\frac{5}{16}$ inch.	179	200	223	246
30	$\frac{3}{16}$ inch.	100	113	125	138
	$\frac{1}{4}$ inch.	133	150	167	184
	$\frac{5}{16}$ inch.	157	187	209	229
32	$\frac{3}{16}$ inch.	94	106	118	128



TABLE XLVII—CONTINUED.

DIAMETER OF BOILER.	THICKNESS OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		40,000	45,000	50,000	55,000
		PRESSURE.	PRESSURE.	PRESSURE.	PRESSURE.
32	$\frac{1}{8}$ inch.	109	122	137	150
	$\frac{5}{16}$ inch.	156	175	196	215
34	$\frac{3}{16}$ inch.	89	100	110	121
	$\frac{1}{2}$ inch.	118	132	148	162
	$\frac{5}{8}$ inch.	148	166	184	203
36	$\frac{3}{16}$ inch.	83	94	104	115
	$\frac{1}{2}$ inch.	110	125	139	152
	$\frac{5}{8}$ inch.	139	156	174	191
38	$\frac{3}{16}$ inch.	79	89	98	108
	$\frac{1}{2}$ inch.	106	119	132	145
	$\frac{5}{8}$ inch.	132	148	164	181
40	$\frac{3}{16}$ inch.	76	84	94	103
	$\frac{1}{2}$ inch.	100	113	125	138
	$\frac{5}{8}$ inch.	125	140	156	172
42	$\frac{3}{16}$ inch.	72	80	89	98
	$\frac{1}{2}$ inch.	95	107	119	131
	$\frac{5}{8}$ inch.	119	134	149	163
44	$\frac{3}{16}$ inch.	68	77	85	94
	$\frac{1}{2}$ inch.	91	102	114	125
	$\frac{5}{8}$ inch.	114	128	142	156
46	$\frac{3}{16}$ inch.	65	73	82	90
	$\frac{1}{2}$ inch.	86	98	109	120
	$\frac{5}{8}$ inch.	109	122	136	150
48	$\frac{3}{16}$ inch.	62	71	78	86
	$\frac{1}{2}$ inch.	84	94	104	115
	$\frac{5}{8}$ inch.	104	118	131	144

TABLE XLVII—CONTINUED.

DIAMETER OF BOILER.	THICKNESS OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		40,000	45,000	50,000	55,000
		PRESSURE.	PRESSURE.	PRESSURE.	PRESSURE.
50	$\frac{1}{4}$ inch.	80	90	100	110
	$\frac{5}{16}$ inch.	100	113	125	138
	$\frac{3}{8}$ inch.	120	134	150	166
52	$\frac{1}{4}$ inch.	77	86	96	106
	$\frac{5}{16}$ inch.	96	108	120	132
	$\frac{3}{8}$ inch.	115	130	144	158
54	$\frac{1}{4}$ inch.	74	83	92	102
	$\frac{5}{16}$ inch.	92	104	115	127
	$\frac{3}{8}$ inch.	112	125	139	152
56	$\frac{1}{4}$ inch.	72	80	90	98
	$\frac{5}{16}$ inch.	90	101	112	122
	$\frac{3}{8}$ inch.	107	120	134	148
58	$\frac{1}{4}$ inch.	68	78	86	95
	$\frac{5}{16}$ inch.	86	97	108	119
	$\frac{3}{8}$ inch.	103	116	130	143
60	$\frac{1}{4}$ inch.	67	76	84	92
	$\frac{5}{16}$ inch.	84	94	104	114
	$\frac{3}{8}$ inch.	100	113	125	138
66	$\frac{1}{4}$ inch.	61	68	76	83
	$\frac{5}{16}$ inch.	76	85	95	104
	$\frac{3}{8}$ inch.	91	102	114	125
72	$\frac{1}{4}$ inch.	55	62	70	77
	$\frac{5}{16}$ inch.	70	78	86	96
	$\frac{3}{8}$ inch.	83	94	104	115

In the tables following, the writer makes a distinction between ordinary iron boiler plate and what is called in the tables "high grade iron." By this is meant flange iron, and what is sometimes called fire box iron; or in other words, the very highest grades of wrought iron plates, by whatever name they may be called. For ordinary shells made of C. H. No. 1 iron, 45,000 to 50,000 pounds is as high a tensile strength as it is safe to assume without testing; the 40,000 pounds iron is not recommended for any service in which high pressures are to be used.

It is not probable that manufacturers will have frequent calls for iron boilers from 60,000 to 70,000 pounds tensile strength. Such irons are made, however, and could be furnished if ordered. There are western river steamboats which have boilers made of iron averaging not far from 65,000 pounds tensile strength. If it is necessary to order this grade of iron for a boiler, samples should be cut from each sheet at the rolling mill, numbered or marked for testing before doing any work on the plate. If the samples (or coupons as they are generally called) do not come up to the required test the sheet is to be rejected. In the case of steel plates the tensile strengths should be chosen from 60,000 to 65,000 pounds tensile strength, and ought not to exceed 70,000, and in no case more than 75,000 pounds. The ordinary temper and bending tests will suffice for steel of the three first grades; for the fourth or last, in addition to these, it should be tested for elongation and contraction of area.

TABLE XLVIII.
SHOWING THE SAFE WORKING PRESSURE FOR SINGLE RIVETED STEEL
OR HIGH GRADE WROUGHT IRON CLYINDER BOILERS, FROM TWENTY-
FOUR TO SEVENTY-TWO INCHES IN DIAMETER, EMPLOYING A FAC-
TOR OF SAFETY OF SIX.

Single Riveted, Steel or Wrought Iron Shells.

DIAMETER OF BOILER.	THICKNESS. OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		60,000	65,000	70,000	75,000
		PRESSURE.	PRESSURE.	PRESSURE.	PRESSURE.
24	$\frac{3}{16}$ inch.	156	169	182	195
	$\frac{1}{2}$ inch.	208	226	243	260
	$\frac{5}{16}$ inch.	260	282	304	325
26	$\frac{3}{16}$ inch.	144	156	168	180
	$\frac{1}{2}$ inch.	192	208	224	240
	$\frac{5}{16}$ inch.	240	260	280	300
28	$\frac{3}{16}$ inch.	134	145	156	167
	$\frac{1}{2}$ inch.	179	193	208	223
	$\frac{5}{16}$ inch.	223	242	260	279
30	$\frac{3}{16}$ inch.	125	135	146	156
	$\frac{1}{2}$ inch.	167	181	194	208
	$\frac{5}{16}$ inch.	208	226	243	260
32	$\frac{3}{16}$ inch.	117	127	137	147
	$\frac{1}{2}$ inch.	156	163	182	195
	$\frac{5}{16}$ inch.	195	212	228	244
34	$\frac{3}{16}$ inch.	110	119	129	138
	$\frac{1}{2}$ inch.	147	159	172	184
	$\frac{5}{16}$ inch.	184	199	214	230
36	$\frac{3}{16}$ inch.	104	113	122	130
	$\frac{1}{2}$ inch.	139	150	162	174
	$\frac{5}{16}$ inch.	174	188	203	217



TABLE XLVIII—CONTINUED.

DIAMETER OF BOILER.	THICKNESS OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		60,000	65,000	70,000	75,000
		PRESSURE.	PRESSURE.	PRESSURE.	PRESSURE.
38	$\frac{3}{16}$ inch.	99	107	115	123
	$\frac{1}{2}$ inch.	132	143	154	164
	$\frac{5}{16}$ inch.	164	178	192	206
40	$\frac{3}{16}$ inch.	94	101	109	117
	$\frac{1}{2}$ inch.	125	135	145	156
	$\frac{5}{16}$ inch.	156	169	182	195
42	$\frac{3}{16}$ inch.	89	97	104	112
	$\frac{1}{2}$ inch.	119	129	139	149
	$\frac{5}{16}$ inch.	149	161	174	186
44	$\frac{3}{16}$ inch.	85	92	99	107
	$\frac{1}{2}$ inch.	114	123	133	142
	$\frac{5}{16}$ inch.	142	154	166	178
46	$\frac{3}{16}$ inch.	82	88	95	102
	$\frac{1}{2}$ inch.	109	118	127	136
	$\frac{5}{16}$ inch.	136	147	159	170
48	$\frac{3}{16}$ inch.	78	84	91	97
	$\frac{1}{2}$ inch.	104	113	121	130
	$\frac{5}{16}$ inch.	130	141	152	162
50	$\frac{1}{2}$ inch.	100	108	116	124
	$\frac{5}{16}$ inch.	124	135	145	156
	$\frac{3}{8}$ inch.	150	162	175	188
52	$\frac{1}{2}$ inch.	96	104	112	120
	$\frac{5}{16}$ inch.	120	130	140	150
	$\frac{3}{8}$ inch.	144	156	168	180

TABLE XLVIII—CONTINUED.

DIAMETER OF BOILER.	THICKNESS OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		60,000	65,000	70,000	75,000
		PRESSURE	PRESSURE.	PRESSURE.	PRESSURE.
54	$\frac{1}{4}$ inch.	93	100	108	116
	$\frac{5}{16}$ inch.	116	125	135	145
	$\frac{3}{8}$ inch.	139	150	162	174
56	$\frac{1}{4}$ inch.	89	96	104	111
	$\frac{5}{16}$ inch.	111	121	130	140
	$\frac{3}{8}$ inch.	134	145	156	167
58	$\frac{1}{4}$ inch.	86	93	100	108
	$\frac{5}{16}$ inch.	108	117	126	135
	$\frac{3}{8}$ inch.	129	140	151	162
60	$\frac{1}{4}$ inch.	83	90	97	104
	$\frac{5}{16}$ inch.	104	113	121	130
	$\frac{3}{8}$ inch.	125	135	146	156
66	$\frac{1}{4}$ inch.	76	82	88	95
	$\frac{5}{16}$ inch.	95	103	110	118
	$\frac{3}{8}$ inch.	114	123	133	142
72	$\frac{1}{4}$ inch.	69	75	81	87
	$\frac{5}{16}$ inch.	87	94	101	108
	$\frac{3}{8}$ inch.	104	113	122	130

A word of caution may not be out of place just here in regard to using thinner plates of steel because of its higher tensile strength; for example: the substituting of a $42 \times \frac{3}{16} \times 70,000$ lbs. shell made of steel, instead of a $42 \times \frac{1}{4} \times 50,000$ lbs. shell made of iron would not be recommended by any boiler maker who cared anything for his reputation, and the reasons are quite obvious, the principal one being



that the tightness of a riveted joint is not increased because of the increased tensile strength of the plates, and it would be a very difficult matter to keep such a boiler tight, especially if of considerable length. The writer does not favor the use of plates less than one-quarter inch thick for boilers when exceeding thirty inches in diameter, whether of steel or iron; neither does he recommend single riveting for boilers of any diameter when constructed of steel or of iron having these high tensile strengths.

TABLE XLIX.

SHOWING THE SAFE WORKING PRESSURE FOR DOUBLE RIVETED STEEL OR HIGH GRADE IRON CYLINDER BOILERS, FROM TWENTY-FOUR TO SEVENTY-TWO INCHES DIAMETER. EMPLOYING A FACTOR OF SAFETY OF SIX, AND ADVANCING THE PRODUCT TWENTY PER CENT. FOR DOUBLE RIVETING.

Double Riveted Iron or Steel Shells.

DIAMETER OF BOILER.	THICKNESS OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		60,000	65,000	70,000	75,000
		PRESSURE.	PRESSURE.	PRESSURE.	PRESSURE.
24	$\frac{3}{16}$ inch.	187	203	218	234
	$\frac{1}{4}$ inch.	250	271	292	312
	$\frac{5}{16}$ inch.	312	338	365	390
26	$\frac{3}{16}$ inch.	173	187	202	216
	$\frac{1}{4}$ inch.	230	250	269	288
	$\frac{5}{16}$ inch.	288	312	336	360
28	$\frac{3}{16}$ inch.	161	174	187	200
	$\frac{1}{4}$ inch.	215	232	250	268
	$\frac{5}{16}$ inch.	268	290	312	335
30	$\frac{3}{16}$ inch.	150	162	175	187
	$\frac{1}{4}$ inch.	200	217	233	250
	$\frac{5}{16}$ inch.	250	271	292	312

TABLE XLIX—CONTINUED.

DIAMETER OF BOILER.	THICKNESS OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		60,000	65,000	70,000	75,000
32	$\frac{3}{16}$ inch.	PRESSURE. 140	PRESSURE. 152	PRESSURE. 164	PRESSURE. 176
	$\frac{1}{4}$ inch.	187	196	218	234
	$\frac{5}{16}$ inch.	234	254	274	293
34	$\frac{3}{16}$ inch.	132	143	155	166
	$\frac{1}{4}$ inch.	176	191	206	221
	$\frac{5}{16}$ inch.	221	239	257	276
36	$\frac{3}{16}$ inch.	125	136	146	156
	$\frac{1}{4}$ inch.	167	180	194	209
	$\frac{5}{16}$ inch.	209	226	244	260
38	$\frac{3}{16}$ inch.	119	128	138	148
	$\frac{1}{4}$ inch.	158	172	185	197
	$\frac{5}{16}$ inch.	197	214	230	247
40	$\frac{3}{16}$ inch.	113	121	131	140
	$\frac{1}{4}$ inch.	150	162	174	187
	$\frac{5}{16}$ inch.	187	203	218	234
42	$\frac{3}{16}$ inch.	107	116	125	134
	$\frac{1}{4}$ inch.	143	155	167	179
	$\frac{5}{16}$ inch.	179	193	209	223
44	$\frac{3}{16}$ inch.	102	110	119	128
	$\frac{1}{4}$ inch.	137	148	160	170
	$\frac{5}{16}$ inch.	170	185	199	214
46	$\frac{3}{16}$ inch.	98	106	114	122
	$\frac{1}{4}$ inch.	131	142	152	163
	$\frac{5}{16}$ inch.	163	176	191	204
48	$\frac{3}{16}$ inch.	94	101	109	116



TABLE XLIX—CONTINUED.

DIAMETER OF BOILER.	THICKNESS OF SHELL.	TENSILE STRENGTH PER SQUARE INCH.			
		60,000	65,000	70,000	75,000
		PRESSURE.	PRESSURE.	PRESSURE.	PRESSURE.
48.	$\frac{1}{4}$ inch.	125	136	145	156
	$\frac{5}{16}$ inch.	156	169	182	194
50	$\frac{1}{4}$ inch.	120	130	139	149
	$\frac{5}{16}$ inch.	149	162	174	187
	$\frac{3}{8}$ inch.	180	194	210	226
52	$\frac{1}{4}$ inch.	115	125	134	144
	$\frac{5}{16}$ inch.	144	156	168	180
	$\frac{3}{8}$ inch.	173	187	202	216
54	$\frac{1}{4}$ inch.	112	120	130	139
	$\frac{5}{16}$ inch.	139	150	162	174
	$\frac{3}{8}$ inch.	167	180	194	209
56	$\frac{1}{4}$ inch.	107	115	125	133
	$\frac{5}{16}$ inch.	133	145	156	168
	$\frac{3}{8}$ inch.	161	174	187	200
58	$\frac{1}{4}$ inch.	103	112	120	130
	$\frac{5}{16}$ inch.	130	140	151	162
	$\frac{3}{8}$ inch.	155	168	181	194
60	$\frac{1}{4}$ inch.	100	108	116	125
	$\frac{5}{16}$ inch.	125	136	145	156
	$\frac{3}{8}$ inch.	150	162	175	187
66	$\frac{1}{4}$ inch.	91	98	106	114
	$\frac{5}{16}$ inch.	114	124	132	142
	$\frac{3}{8}$ inch.	137	148	160	170
72	$\frac{1}{4}$ inch.	83	90	97	104
	$\frac{5}{16}$ inch.	104	113	121	130
	$\frac{3}{8}$ inch.	125	136	146	156

Collapsing pressures—The best experimental data relating to the collapsing pressures for flues or tubes are those of Sir William Fairbairn. The pressure necessary to collapse a flue was found to vary nearly according to the following laws:

Inversely as the length.

Inversely as the diameter.

Inversely as a function of the thickness, which is nearly the power whose index is 2.19; but which for ordinary practical purposes may be treated as sensibly equal to the square of the thickness.

By these formulas the 2.19 power of the thickness multiplied by 806,300, and divided by the product of diameter in inches by the length in feet, is undoubtedly correct for thin flues of certain lengths. The 2 power of the thickness is also correct for another class of thicker flues. In the following tables both of these formulas are used—the 2.19 in the right hand triangle, and the 2 in the left. Neither of these formulas appear to apply to heavy flues of great lengths. This, to a certain extent, is on account of the laps acting upon the principle of Fairbairn's bands.

In the tables of internal pressure, one-fifth of the value of ordinary boiler iron (say 50,000 pounds to the inch of section) is taken to be safe; while in the external one-third is taken; this is on account of the great variation in the tensile strength of iron.

NOTE—Headings to Tables L and LI should read, "*Showing Safe Working Pressures against Collapse,*" according to Fairbairn's formula, etc.

TABLE L.
SHOWING COLLAPSING PRESSURES ACCORDING TO FAIRBAIRN'S FORMULA. FLUES TEN FEET LONG—BUTT-JOINTS.

BIRMINGHAM GAUGE.	0	1	2	3	4	5	6	7	8	8
THICKNESS OF IRON.	0	1	2	3	4	5	6	7	8	8
INCHES.	0	1	2	3	4	5	6	7	8	8
6	629.92	517.82	381.29	301.49	253.73	216.81	184.59	145.14	121.95	86.60
7	539.03	443.85	313.96	257.56	217.49	183.83	158.22	124.40	104.53	74.23
8	472.44	388.37	270.97	225.36	190.30	162.60	138.45	108.85	78.38	64.96
9	419.95	345.22	240.86	200.32	169.16	140.83	123.16	98.76	69.83	57.73
10	377.95	310.69	216.78	180.29	152.24	128.08	110.76	87.06	62.96	51.96
11	343.69	282.45	219.66	163.90	138.40	118.26	100.69	74.37	57.15	47.23
12	314.12	258.91	201.58	150.24	126.87	108.40	92.30	68.17	51.89	43.50
13	290.73	238.99	186.07	138.69	117.11	100.06	85.20	62.93	48.36	39.96
14	269.97	221.92	172.78	128.76	108.74	92.92	78.72	58.43	44.90	37.11
15	251.97	207.13	161.26	120.19	101.49	86.72	73.80	54.64	41.91	34.65
16	236.22	194.18	151.18	112.68	95.15	81.30	68.18	51.13	38.98	32.44
17	222.33	182.76	142.28	106.03	89.35	77.38	64.39	48.12	36.96	30.56
18	209.97	172.61	134.38	100.16	84.58	73.95	61.00	45.45	34.93	28.86
19	198.92	163.52	127.72	94.89	80.13	69.74	57.95	43.06	33.08	27.35
20	188.98	155.35	120.95	90.15	75.44	66.42	55.19	40.66	31.43	25.98
21	179.98	147.95	115.19	85.83	70.71	63.40	52.68	38.96	29.93	24.74
22	170.28	141.23	108.39	81.95	66.44	60.64	50.39	37.19	28.68	23.62
23	164.33	135.08	103.23	78.55	63.40	58.12	48.29	35.87	27.83	22.68
24	157.48	129.46	98.76	74.20	60.64	56.35	46.36	34.09	26.20	21.65
25	151.18	124.28	94.26	71.11	58.12	54.79	44.58	32.72	25.15	20.78
26	146.37	119.59	90.58	68.27	56.79	53.21	42.93	31.46	24.18	19.98
27	139.98	115.07	86.39	65.21	55.65	51.66	41.39	30.30	23.28	19.25
28	134.98	110.96	83.03	63.21	53.64	49.81	39.57	29.22	22.45	18.56
29	130.33	107.14	80.58	61.35	51.85	48.10	38.53	28.21	21.68	17.92
30	125.98	103.56	78.28	59.66	50.20	46.49	36.22	27.27	20.96	17.32
32	118.11	97.09	73.10	56.89	48.14	43.59	34.09	25.57	19.65	16.24
34	111.16	91.16	68.61	53.45	45.34	41.02	32.19	24.06	18.49	15.17
36	104.99	86.61	64.31	50.61	44.91	38.74	30.50	22.72	17.46	14.43
38	99.46	82.28	60.27	48.11	42.67	36.70	28.98	21.53	16.54	13.67
40	94.49	78.42	57.32	45.82	40.63	34.87	27.60	20.45	15.72	12.99
42	89.99	73.32	54.21	43.82	38.63	33.21	26.60	19.48	14.97	12.37
INCH.	0	1	2	3	4	5	6	7	8	8
H. W. GAUGE.	0	1	2	3	4	5	6	7	8	8
INCH.	0	1	2	3	4	5	6	7	8	8
H. W. GAUGE.	0	1	2	3	4	5	6	7	8	8

TABLE I.I.
SHOWING COLLAPSING PRESSURES ACCORDING TO FAIRBAIRN'S FORMULA. FLUES TWENTY FEET LONG—BUTT-JOINTS.

BIRMINGHAM GAUGE. THICKNESS OF IRON. INCHES.	200	0	1	2	3	4	5	6	7	8	8
	.375	.340	.300	.284	.259	.238	.220	.203	.180	.165	.163
6	314.96	258.91	201.58	180.65	159.25	126.87	108.40	92.30	72.57	60.98	43.30
7	269.97	221.93	172.78	156.98	138.78	108.75	92.92	79.11	62.20	52.27	37.12
8	236.22	194.18	151.18	135.41	112.68	93.15	81.30	69.22	54.43	45.27	32.48
9	209.97	172.61	136.98	120.43	100.16	84.58	70.42	61.53	48.38	34.93	26.87
10	188.98	155.85	120.93	108.39	90.15	76.12	65.04	55.98	43.54	31.43	25.98
11	171.80	141.26	109.78	96.90	81.95	69.20	59.13	50.85	39.78	28.58	23.62
12	157.06	129.46	100.79	90.32	75.12	63.44	54.20	46.15	34.08	26.19	21.15
13	145.37	119.50	93.03	83.38	69.35	58.56	50.03	42.60	31.47	24.18	19.98
14	134.98	110.96	86.39	77.42	64.79	54.37	46.46	39.43	29.22	22.45	18.56
15	125.98	103.56	80.63	72.26	60.10	50.75	43.36	36.46	27.27	20.96	17.33
16	118.11	97.09	75.69	67.74	56.34	47.58	40.65	34.09	25.67	19.65	16.24
17	111.16	91.38	71.14	62.53	53.03	44.78	38.20	32.20	24.10	18.49	15.28
18	104.99	86.31	67.19	60.22	50.08	42.29	35.66	30.50	22.73	17.47	14.43
19	99.46	81.76	63.85	57.05	47.45	40.67	33.87	28.98	21.53	16.54	13.68
20	94.49	77.68	60.47	54.19	45.08	38.20	32.20	27.60	20.45	15.77	12.99
21	89.99	73.98	57.50	51.61	42.93	35.21	29.32	25.30	19.48	14.97	12.38
22	85.14	70.62	54.98	49.27	40.98	33.70	28.32	24.15	18.59	14.29	11.81
23	82.16	67.54	52.58	47.13	39.56	32.10	27.06	23.18	17.78	13.67	11.29
24	78.74	63.73	50.29	45.16	38.14	30.70	25.96	22.29	17.04	13.10	10.83
25	75.59	62.14	48.38	43.36	36.76	29.66	25.06	21.55	16.36	12.68	10.39
26	72.68	59.72	46.52	41.66	35.41	28.82	24.38	20.70	15.73	12.19	9.99
27	69.99	57.54	44.56	39.99	34.14	28.03	23.81	20.17	15.15	11.64	9.63
28	67.49	55.48	43.20	38.43	32.93	27.43	23.45	19.99	14.62	11.23	9.28
29	65.17	53.57	41.78	36.99	32.07	26.85	23.25	19.22	14.11	10.84	8.96
30	62.99	51.78	40.55	35.64	31.18	26.43	22.80	18.76	13.63	10.48	8.66
32	59.06	48.55	38.22	33.22	29.07	25.07	21.80	18.11	13.03	9.83	8.12
34	55.58	45.58	36.22	31.66	27.30	23.71	20.51	17.05	12.03	9.25	7.59
36	52.50	43.73	34.32	29.82	25.82	22.46	19.37	16.10	11.35	8.73	7.32
38	49.73	42.04	32.64	28.32	24.06	21.34	18.35	15.25	10.77	8.27	6.84
40	47.24	39.21	31.04	26.82	22.91	20.32	17.44	14.49	10.23	7.86	6.50
42	44.99	36.66	30.14	25.32	22.01	20.32	16.61	13.80	11.62	7.49	6.19
INCH.				0	1	2	3	4	5	6	8
B. W. GAUGE.	.375	.375		.340	.300	.264	.220	.238	.250	.300	.165

The pressures along the diagonal space show the effect of these two formulas on the same diameter, length and thickness; also, the comparative strength of thick and thin flues of the same length and different diameters, viz, a flue thirty-six inches in diameter, three-eighths thick, ten feet long, is about as strong as one seven inches diameter, 1.65 inches thick, of the same length.

The resistance to collapse depends very much on the flues being exactly cylindrical, and it is for this reason that all large ^{flues} tubes intended for internally fired boilers should be fitted with butt riveted, instead of lap riveted joints. Mr. Fairbairn found that the flues were greatly strengthened by riveting angle or T iron rings at regular distances on the flues; and as the collapsing resistance is very much less than the safe working internal pressure, these rings could be applied until the bursting and collapsing pressures equaled each other. Whenever practicable, the thickness of metal in the flue and in the shell ought to be the same. In very large boilers this can not be done. Instead of the rings spoken of above, it is now the practice of many boiler makers to use welded flues in short lengths; joining the ends, and then riveting together in much the same way that flanged cast iron pipes are bolted.

In regard to small tubes, the following table may often be found useful. It is taken from D. K. Clark's Manual of Rules, Tables and Data:

TABLE LII.
SOLID DRAWN IRON TUBES—CALCULATED BURSTING AND COLLAPSING
PRESSURES.

EXTER- NAL DIAME- TER.	THICKNESS.		INTER- NAL DIAME- TER.	BURSTING PRESSURE.		COLLAPSING PRESSURE.	
	B.W.G	INCH.		PER SQ. IN. OF INTERNAL SURFACE.	PER SQ. INCH OF SECTION OF METAL	PER SQ. INCH OF EXT'RNAL SURFACE.	PER SQ. INCH OF SECTION OF METAL
INCHES			INCHES.	POUNDS.	TONS.	POUNDS.	TONS.
1½	14	.083	1.084	7,700	22.4	6,500	21.7
1¾	14	.083	1.209	6,900	22.4	5,800	21.3
1½	14	.083	1.334	6,200	22.4	5,200	21.0
1¾	14	.083	1.459	5,700	22.4	4,700	20.7
1¾	14	.083	1.584	5,300	22.4	4,300	20.3
1¾	14	.083	1.709	4,900	22.4	4,000	20.0
2	14	.083	1.834	4,500	22.4	3,700	19.7
2½	13	.095	1.935	4,900	22.4	3,800	19.3
2½	13	.095	2.060	4,600	22.4	3,600	19.0
2½	12	.109	2.282	4,800	22.4	3,600	18.3
2¾	12	.109	2.532	4,300	22.4	3,100	17.7
3	11	.120	2.760	4,400	22.4	3,000	17.0
3½	11	.120	3.010	4,000	22.4	2,700	16.3
3½	10	.134	3.232	4,200	22.4	2,700	15.7
3¾	10	.134	3.482	3,900	22.4	2,400	15.0
4	10	.134	3.732	3,600	22.4	2,100	14.3
4½	10	.134	3.982	3,400	22.4	1,900	13.7
4½	10	.134	4.232	3,200	22.4	1,700	13.0
4¾	10	.134	4.482	3,000	22.4	1,600	12.3
5	10	.134	4.732	2,800	22.4	1,400	11.7
5½	9	.148	5.204	2,800	22.4	1,200	10.3
6	9	.148	5.704	2,600	22.4	1,000	9.0

Stay bolts—The sides of locomotive and portable engine fire boxes have a greater or less extent of flat surface, sub

ect to both external and internal pressures. These surfaces are opposite each other, and are kept in place by screwed stays, riveted over the ends. Each of these bolts or stays sustains the pressure of steam against a certain area of the plate to which they are attached. In some tests made by Mr. Fairbairn on three-quarter inch iron stay bolts with enlarged ends screwed into an iron plate three-eighths inch thick, and then riveted over, it was found that such a stay would resist 30,000 pounds breaking weight. If we allow a factor of safety of six this would give 5,000 pounds as the safe load on a single stay for the diameter and thickness of plate, as given above.

In tests of stayed ends similar to those of fire boxes for portable engines, Messrs. Greig and Eyth experimented on three drums, in which one end plate, representing the inside of the fire box was of three-eighths inch plate; the other, corresponding to the outside shell, was nine-sixteenths inch. This greater thickness was not required by the boiler as such, but is employed in the special case of steam plowing or traction engine boilers where this side plate carries part of the machinery.

The stays were seven-eighths inch in diameter, four and a quarter inches apart, and in drums Nos. 1 and 2 were riveted over the ends on both sides. They were tapped right through, having fourteen threads per inch. One of these drums (1) was entirely of steel, the other (2) of iron. The third drum was of steel, with check nuts on the end of the stays on the side of the weaker plate. The clear space between the two plates was two and a half inches wide, exactly corresponding to the water space of the fire box.

The iron barrel (No. 2) failed with a pressure of 1,230 pounds per square inch. In this case one of the outside stays gave way; the first signs of the failure appeared with a pressure of about 1,150 pounds, when the edges of the

rivet head of the stay crumbled away. The plate bulging out between the stays, the one which failed slipped gradually and noiselessly through the hole of the thinner plate, through which the water then escaped. The section of the solid part of the stay (minus the thread) having a diameter of barely $\frac{1}{8}$ inch, is 0.51 square inch. The tensile strength of the iron employed was 22.23 tons per square inch, and a stay ought therefore to carry 11.34 tons, or 25,400 pounds. The area supported by the stay should have been $4\frac{1}{4}$ inches square, or 18.06 square inches. In this case the riveted head of the stay gave way at twelve per cent below its regular breaking strain.

The steel drum (No. 1) broke under a pressure of 1,628 pounds per square inch. In this case a stay broke fairly in the middle between the two plates with a loud report, the plates bulging out freely. In this case, as before, the area supported by one stay is 16.06 square inches, so that the maximum pressure put on one stay amounted to 29,402 pounds. The sectional area is as before, 0.52 square inch, and the breaking strain of the steel employed is 64,579 pounds per square inch. The stay ought therefore to be able to carry 33,581 pounds, but as it carried only 29,402 pounds, it broke with a strain twelve per cent less than its maximum tensile strength.

The experiment with the stays provided with nuts was a failure; but there is no doubt that the tendency to bulge is considerably checked by nuts. Many locomotive builders are now using them on the projecting ends of stay bolts and the practice seems to be growing in favor in Europe rather than in this country.

The usual practice of staying flat crown sheets is by means of crown bars and bolts, which is, all things considered, a very objectionable method of staying, owing to the accumulation of deposit underneath and between the bars. A much better way is to use round stays



drawn into the crown sheet and riveted over, or fitted with nuts.

The diameter of stay bolts is usually three times the thickness of the plates for one-quarter and five-sixteenths inch plates, and from two to two and a quarter diameters for half inch and five-eighth plates. They are arranged in vertical rows at a distance of four to four and a half inch centers in the best locomotive practice. In portable engines where the pressures are much lower, say about one-half less, they are usually placed at from four and a half, to five inch centers, depending on the thickness of the metal. It is not customary to take into account the tensile strength of the plates composing the shell or fire box, as the whole pressure is assumed to be upon the stay bolts.

TABLE LIII.

GIVING PROPORTIONS FOR STAY BOLTS FOR FLAT SURFACES.

PRESSURE PER SQ. INCH.	CENTER TO CENTER OF STAY BOLTS, IN INCHES.				
	$\frac{1}{4}$ IN. PLATE.	$\frac{5}{16}$ IN. PLATE	$\frac{3}{8}$ IN. PLATE.	$\frac{7}{8}$ IN. PLATE	$\frac{1}{2}$ IN. PLATE.
	$\frac{3}{4}$ IN. STAY.	$\frac{3}{4}$ IN. STAY.	$\frac{7}{8}$ IN. STAY.	1 IN. STAY.	$1\frac{1}{4}$ IN. STAY.
50	6	7	8	9	10
60	$5\frac{1}{2}$	$6\frac{1}{2}$	$7\frac{1}{4}$	$8\frac{1}{4}$	9
70	5	$5\frac{1}{2}$	$6\frac{1}{2}$	$7\frac{1}{2}$	$8\frac{1}{2}$
80	$4\frac{1}{2}$	$5\frac{1}{2}$	$6\frac{1}{4}$	$7\frac{1}{4}$	$7\frac{1}{2}$
90	$4\frac{1}{2}$	$5\frac{1}{2}$	$5\frac{1}{2}$	$6\frac{1}{2}$	$7\frac{1}{2}$
100	$4\frac{1}{2}$	$4\frac{3}{4}$	$5\frac{1}{2}$	$6\frac{1}{2}$	7
110	4	$4\frac{1}{2}$	$5\frac{1}{4}$	$5\frac{1}{2}$	$6\frac{1}{2}$
120	$3\frac{1}{2}$	$4\frac{1}{4}$	5	$5\frac{1}{4}$	$6\frac{1}{2}$
130	$3\frac{1}{2}$	$4\frac{1}{4}$	$4\frac{1}{2}$	$5\frac{1}{2}$	$6\frac{1}{4}$
140	$3\frac{1}{2}$	$4\frac{1}{4}$	$4\frac{1}{2}$	$5\frac{1}{4}$	6
150	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$

The preceding table gives the results of a comparison of several formulas and dimensions taken from the best practice, and thus fixing the average proportions for diameter of stays based on the thickness of metal and distance apart from center to center for pressure, as given in the first column. It will be understood that this table is empirical and varies only from the well known formula $s = \sqrt{\frac{4000 \times A}{P}}$ by taking into account the stiffness of the plates between supports.

In staying boiler heads, it is the usual practice to rivet an angle or T iron to the head, and attach stay rods or braces running from this piece to some part of the shell or through to the other end of the boiler. There should be some arrangement by which these stay rods may be brought into tension; a link and key is perhaps as good as any, and almost anything is better than a screw, as the threads are apt to waste away if in the steam space, and to be covered with scale if in the water space, so as to practically render them useless after the first application, before cleaning, should it be necessary to remove them for cleaning. The size of the stay rods may be determined by first fixing upon the number that are to be used; the area under pressure to be supported, divided by the number of stays, will give the load upon each. No stay rod should have a load upon it greater than 4,000 pounds per square inch. Thus the diameters of the stay rods may be easily arrived at.

As has been already said, the area taken up by the tubes or flues in the boiler heads reduces the total pressure on the heads by just that amount. Large flues are always riveted to the heads, and thus act as stays. Sometimes both the heads are flanged, as shown in figure 33, on page 141, in which case the flues are simply straight cylinders; at other times one head only is flanged in this manner, the

other head being cut out to receive the flue, which has a flanged end not unlike that on a cast iron pipe; this flange on the flue is brought up against the head and both riveted together, the other end of the flue being riveted as described above. Tubes less than five inches diameter are expanded by special tools into plain smooth holes bored out in the heads: these also act, in a less degree, however, as stays by the slight "bead" or riveting over of the tubes on the outside of the heads.

The Prosser tube expander, as in general use, is shown in elevation in figure 34. It consists of a number of steel



FIGURE 34.

pieces with radial joints, the whole being so arranged that the tool may be inserted in the tube, and by driving on the end of the tapered steel pin passing through the center of these steel pieces, they are forced out radially, and thus by successive operations stretch the end of the tube until it accurately fills the hole. The expander is made partially concave near the end, the length of this groove approximating the thickness of the head and about three times the thickness of the tube. Tubes put in by this method being expanded on both sides of the tube plate in one operation, serve as braces and tend greatly to stiffen the head. Before the tubes are put in place they should be carefully cut to length before expanding, as the chipping off the end of the tube in place is not only unworkmanlike, but there is

danger of splitting the tube. It sometimes happens, the heads are not perfectly flat, and the inside will require to be somewhat shod than those nearer the flanged end. For this another tool is made, an well adapted for the purpose, figure being a sectional elevation, figure perspective view of the ring for shodding the tube, and figure 37 a representation of the expander complete.



FIGURE 35.

The patent combined tube expander and cutter consists of a Prosser expander, the outside bead of which has a cutting edge, also a collar with cutting edges inside. The two cutting edges act as a shear, making a clean square

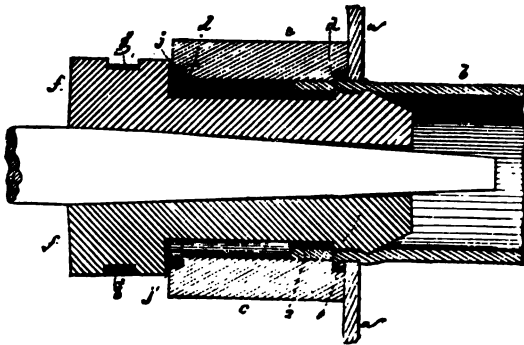


FIGURE 36.

cut from end of tube. This method of cutting off end of tubes will be found to be a great improvement over usual practice of cutting them off with a chisel.

To expand and cut off a tube, the collar is placed at the end of the tube and against the tube plate *a*. The expander and cutter is then inserted within the tube and the gauges *j*, which are shown as shoulders on the expander, meet the end of the collar, in which position

cutting edges *i* are in proper position with reference to the cutting edge of the collar. When in this position the taper-



FIGURE 73.

ing mandrel is driven in and from time to time rotated until a suitable portion of the end of the projecting tube is cut off and the tube at the plate is properly expanded. About one-eighth of an inch of the tube end is left projecting beyond the plate *a*, and the piece cut off is left within the collar. When the collar and tube are removed, the projecting end is properly calked against the plate.

The calking tool employed in finishing the ends of the tubes is shown in figure 38.



FIGURE 38.

Dudgeon's roller tube expander is shown in figure 39, and is designed to properly expand the tube by means of a continuous rotary pressure, and thus lessen the liability of splitting the tubes by driving in a conical or other expand-



FIGURE 39.

ing device. Tubes can be expanded without striking a blow on them, thus rendering them far less liable to crack. Leaky ones can be tightened, with steam on the boiler.

with perfect safety. One expander will answer for any thickness of tube sheet, thus avoiding the necessity of an expander for each different thickness of sheet. They are no more liable to break than the common tool, and are easily kept in order, as the rollers are the only things that can give out, and they can be replaced in a few moments by unscrewing the cap, B.

Steam domes—The strength of boilers is often lessened by cutting out large holes in the shell for steam domes. What particular function this appendage plays in ordinary stationary boilers, would be hard to divine on any economic grounds. The writer confesses to having put hundreds of them on boilers in which they served no more useful purpose than if they had been placed on the steam chest of the engine instead. It sometimes happens that commercial requirements come in conflict with the judgment of the engineer, and, as is too often the case, the latter has to submit to the former. A steam dome is just such a case in point.

The common argument in favor of a steam dome is that it increases the steam room of the boiler. Suppose it does; why the necessity of this increase? If the boiler shell is too small, then an increase of steam room might under some conditions be a good thing; but whether it will increase the efficiency of the boiler by a better circulation of water, or, by a freer liberation of the steam in the water, ought, but seldom is taken into account. If what a steam dome costs were put into a larger shell, leaving the arrangement, size and number of tubes or flues the same, it would be a positive gain in strength not only, but in economy.

The shell of the boiler is weakened in the first place, by cutting out a large hole over which the dome is to be placed. In a very large percentage of cases this hole is

ten times larger in area than there is any necessity for. Why a hole sixteen inches in diameter should be cut in the shell of a boiler and leading into a dome which would not hold half a barrel, and then attaching a three inch pipe to conduct the steam to the engine, is probably beyond the boundary of satisfactory explanation. This is in itself bad enough, but in the second place, in addition to this there is a row of rivet holes, usually two and a half to three inches in diameter larger than the dome, thus still further weakening the metal around the hole.

Some establishments have special drilling machines for drilling these holes; this is the exception rather than the rule. The usual way is to flange the dome and fit it to the shell; the dome is then drilled and the shell marked from these holes. The dome being removed, the holes are cut through the shell with a chisel, then reamed, drifted or chipped, so as to allow the rivet to enter. In fibrous iron it is not an infrequent occurrence to split the plates around the holes. The lower lamina of the plate is almost sure to be loosened or driven into the interior of the boiler. If there is anything within the whole range of mal-treatment to which boilers are subjected which at all approaches the average fitting a dome to a shell, the writer has failed to detect it.

If a dome must be put on a boiler in order to make a sale, the hole leading from the shell into the dome ought not to greatly exceed twice the area of the pipe leading to the engine. Figure 40 shows the idea clearly. This has been the practice of the writer, and has never, to his knowledge, given any trouble. A small hole should be cut through the shell on each side, at a point just inside of the sides of the dome, to drain any water of condensation which might collect there back into the boiler.



FIGURE 40.

If a dome must be put on a boiler, it ought to be of such a size as to appear well in proportion to the whole. The diameter of the boiler naturally suggests itself as that portion by which to fix the diameter of the dome. The following table gives the sizes generally used by the writer, when no particular size is included in the contract; the thickness of the metal in the dome sheet being one-quarter inch at the top and five-sixteenths of an inch at the bottom. These sheets are rolled thicker at the bottom to give more metal where the flange is to be formed.

TABLE LIV.
PROPORTIONS FOR STEAM DOMES.

DIAMETER OF BOILER	SIZE OF DOME.		DIAMETER OF BOILER.	SIZE OF DOME.	
	DIAMETER.	HEIGHT.		DIAMETER.	HEIGHT.
INCHES.	INCHES.	INCHES.	INCHES.	INCHES.	INCHES.
24	12	15	44	26	26
26	13	16	46	28	26
28	15	17	48	28	28
30	16	18	50	30	30
32	18	20	52	32	32
34	18	20	54	32	32
36	20	22	56	34	34
38	22	22	58	34	34
40	24	24	60	36	36
42	24	24			

A steam drum, as shown in figure 41, is to be preferred to a dome riveted to the shell; the opening in the boiler is less, there are fewer rivet holes and these are confined to a smaller diameter. The interior diameter of the nozzles may be, for boilers from

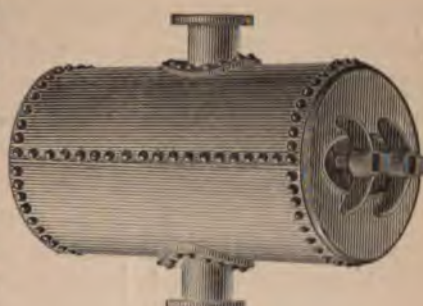


FIGURE 41.

24 to 44 inches diameter.....	4 inches.
46 to 50 inches diameter	5 inches.
52 to 60 inches diameter	6 inches.

The metal in the nozzles should be about an inch thick, not for strength to resist the pressure of steam, but the better to withstand the effects of rough handling, etc. The diameters of the drums for any given boiler may be the same as given in table LIV for domes, and in length they may be two diameters, to look well.

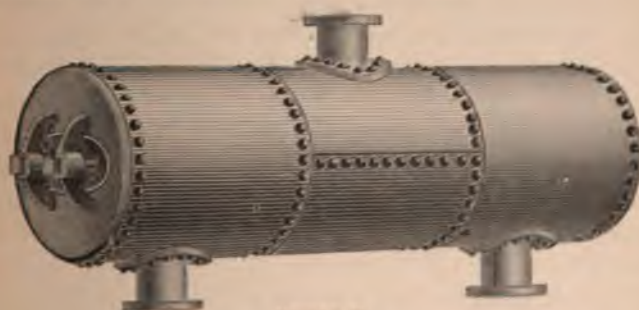


FIGURE 42.

If a boiler really needs more steam room, then a drum should be of sufficient size to make it a useful appendage. In such a case, a drum as shown in figure 42 is recommended.

In regard to size, it may be half the diameter and not less than half the length of the boiler to which it is to be applied. It should be placed midway on the boiler, and have the nozzles connecting the drum with the interior of the boiler, as shown.

Man holes, when cut into the circumferential part of the boiler, are a source of weakness. A man hole should never be placed there, if it is possible to get it into either head. In any ordinary flue or tubular boiler it can be placed

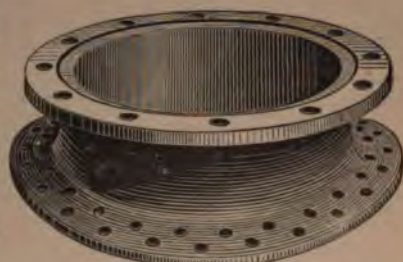


FIGURE 43.

in the head, as shown in figure 43, without interfering with anything about the boiler, either externally or internally. When man holes are placed in the heads, there should be one below the tubes or flues, if possible, and one above them. This will in most cases allow ample facility for cleaning or repairs. There should be in all cases a heavy wrought iron ring riveted around the hole. Many boiler makers neglect this altogether, and many who do put in such a ring make it so light as to be of little or no service in strengthening the head. The writer has seen rings around man holes in which the net sectional area of the ring through the center of any given hole was scarcely more than the area of metal punched out of the head, for the insertion of a rivet by which it was to be attached to the head. This is all wrong, and the boiler would lose little or nothing in strength if the ring were left off altogether.

When it is impracticable to put the man holes in the heads, then the shell should be strengthened by a heavy ring, which may be riveted to the inside of the boiler and the man hole plate make its joint on the ring itself. A very common practice is to make a cast iron "saddle," with a flange to fit the boiler, and a portion of the casting

carried up high enough to make a flat joint for the man hole plate on its inner side. Such a device needs to be recommended with some caution. A cast iron fitting around a hole, say ten by sixteen inches, in the shell of a boiler, while it may not be dangerous, should not be accepted as perfectly safe. The following engraving, figure 43 $\frac{1}{2}$, represents a form of exterior wrought iron fitting for man holes, by W. & J. Galloway, Manchester, England. This is an excellent device for the purpose, and one which it would be well to adopt in this country. It is possible that wrought iron rings are so applied in this country, but the writer has not seen them.

FIGURE 43 $\frac{1}{2}$.

Sometimes a steam dome is fitted with a cast iron head and the man hole plate is fitted in it. In such a case the opening into the dome from the interior of the boiler should have a heavy wrought iron ring, as already described in a preceding paragraph.

CHAPTER IX.

HEATING SURFACE AND BOILER POWER.

Transfer of Heat—Radiation—Conduction—Convection—Heating Surface, Internal, External—Position of Heating Surface—Heating Surface of Tubes and Flues—Evaporation as Modified by Heating Surface, in Kind and Extent—Relation of Grate Area to Heating Surface—Evaporation Modified by the Circulation of Water in the Boiler—Boiler Power—Evaporative Capacity and Economy—Efficiency of a Boiler—Rating of Boiler Power.

Transfer of heat—This is accomplished by radiation, conduction, convection. Radiation, considered as a mode of transference of heat, is a process which can only go on between at least two material bodies, one of which gives out, and the other receives heat. The phenomena of radiant heat have been studied, and its laws well ascertained, and, as a luminous body sends out rays of light in all directions, in straight lines, so also does a heated body send out rays of heat in all directions, in straight lines. These rays of heat, like those of light, may be reflected and refracted, and seem in all respects to be identical, with the exception that the former is known to us only through the sensation of feeling, or are measurable by means of a thermometer, while the latter is made known through the organ of sight. Rays of radiant heat, always moving in straight lines when the medium through which it passes permits it, do not impart any heat to a surrounding medium by diffusion, and thus materially differs from conduction of heat, in which the heat always travels from hotter to colder portions of an unequally heated medium. The

entire process of radiation consists of three distinct parts—emission, absorption and transmission.

Emission of radiant heat—Radiant heat is emitted in straight lines in all directions from a radiating point. Hence, the *quantity* of heat which, in a given time, falls on a given substance from a radiating point is inversely proportional to the square of the distance of that surface from the radiating point.

It is a matter of universal experience that, under otherwise similar circumstances, a given body gives out more heat in a given time the hotter it is. Temperature, therefore, is one condition which determines the emissive power of bodies for heat; but further examination shows that it is not the only condition upon which this phenomenon depends, as it is well known that different substances have very different powers of emitting heat, even when their temperatures are exactly the same.

Absorption of radiant heat—When radiant heat arrives at the surface of a boiler, for example, part of it is always reflected, either regularly or diffusively; but this reflection is never complete. Another portion of the heat penetrates into the iron, and, according to the particular properties of the latter, is either wholly or in part transmitted through it, or is wholly or in part annihilated, causing an increase of temperature in the body. It is this extinction of radiant heat, in causing rise in temperature in material bodies, that constitutes the phenomenon of absorption.

TABLE I.V.
COMPARATIVE RADIATING OR ABSORBENT AND REFLECTING POWERS OF
SUBSTANCES.

SUBSTANCE.	POWERS.	
	RADIATING OR ABSORBING.	REFLECT- ING.
Water.....	100	0
Ice.....	85	15
Cast iron, brightly polished.....	25	75
Wrought iron, polished.....	23	77
Zinc, polished.....	19	81
Steel, polished.....	17	83
Tin.....	15	85
Brass, cast, bright polished.....	7	93
Copper, hammered or cast.....	7	93

The reflecting power of a body is the complement of its absorbing power. The latter varies with the nature of the source of heat, with the condition of the substance, and with the inclination of the direction of the heat radiated upon the body. The absorbing power of a metallic surface is much less than the reflecting power, and the latter increases as the surface is highly polished.

Radiation of heat from combustibles—Few experiments have been made to determine the proportion which the radiant heat bears to the total heat in different combustibles. M. Peclet, by means of a simple apparatus, consisting of a cage suspending the combustibles within a hollow cylinder filled with water in an annular space, ascertained that the proportion of the total heat radiated from different combustibles was as follows :

Total heat.....	100
Radiant heat from wood.....	25 per cent, nearly.
Radiant heat from charcoal.....	50 per cent, nearly.
Radiant heat from oil.....	20 per cent, nearly.

The transmission of radiant heat is controlled by the same laws as that of light, and has its origin in the oscillatory motion of the ultimate particles of matter. Transmission consists, then, in the transference of this motion from a heated body called the emissive to another called the absorbing body. This transmission never occurs except when heat passes out of a hot body to enter a colder one.

Conduction is the transfer of heat between two bodies or parts of a body which touch each other. It is distinguished into *internal* and *external* conduction, according as it takes place between the parts of one continuous body, or through the surface of contact of a pair of distinct bodies.

If one part of a body, such as a bar of iron, is at a higher temperature than the rest, and it be left to itself, it will in time acquire a uniform temperature throughout the mass of metal, the hot part losing heat, the cold part gaining heat. This tendency towards equalization of temperature is what is known as internal conduction of heat.

The rate at which conduction, whether internal or external, goes on, being proportional to the area of the section or surface through which it takes place, may be expressed in the form of *so many thermal units per square foot of area per hour*. [Rankine].

The following table gives the comparative conducting power of different metals:

Silver	100.0
Copper.....	73.6
Brass.....	23.6
Tin.....	14.5

Iron.....	11.9
Steel.....	11.6
Lead.....	8.5
German Silver.....	6.3

As a general rule it will be found that the densest bodies are the best conductors of heat.

Conduction of heat by liquids—In consequence of the diminution of density which takes place almost universally in liquids when they are heated, an increase of temperature is rapidly communicated by convection to the whole of a quantity of liquid when heat is applied to it from below. Hence, it was formerly supposed that liquids possessed a high degree of conductivity for heat. When heat is imparted to a liquid from above, so that the expansion of the heated portions can not cause them to rise, and so produce a circulation of the liquids, the communication of heat from one part of a liquid to another takes place with extreme slowness; and thus heat acts for a long time upon the upper part of a column of water and gradually penetrates downwards and follows the same law of conduction as observed in metals, being only less in degree. From experiments it appears that the conductivity of water is to that of copper as 9 to 1000.

Convection of heat, means the transfer and diffusion of the state of heat in a fluid mass, by means of the motion of the particles of that mass. It is only by the continual circulation and mixture of the particles of the fluid, that uniformity of temperature can be maintained in the fluid mass, or heat transferred between the fluid mass and a solid body. In a steam boiler, it is favorable to economy of fuel that the motion of the water and steam should, on the whole, be opposite to that of the flame and hot gas from the furnace.

Heating surface—One of the first things to be known, after the selection of a particular type of boiler, is the amount of heating surface it ought to have to evaporate a certain quantity of water. As the evaporation is dependent largely upon the construction of the boiler itself, together with its furnace, whether situated within itself or underneath it, there is an element of uncertainty as to quantity, introduced at a very early stage in any proposed calculations.

Internal heating surface—The most effective heating surface in a boiler is a flat or concave plate or crown sheet, immediately over the fire. For several reasons, a concave plate, acting as a crown sheet, is to be preferred whenever practicable, on account of its being well adapted to receive the radiant heat from the fire, but more especially on account of its permitting a better circulation of water inside the boiler, because of the absence of crown bars and other fixtures necessary to the proper staying of a large, flat surface.

In this case, the fire is made in a furnace, surrounded on all sides, except the bottom, with water spaces.

The relative values of heating surfaces in the different portions of a boiler can not be said to have been definitely settled. It is generally known, however, that in fire box boilers, for example, by far the greater portion of the evaporation is carried on in the fire box end of the boiler.

External heating surface—In horizontal tubular boilers the shell is far more efficient than the tubes. The *efficiency* and the *quantity* of heating surface in a boiler should never be confounded, and in designing a boiler, the former of the two is always to be preferred over the latter. The generally received notion that a boiler should present no heat absorbing surfaces to obstruct the flow of heated gases,

borders on an absurdity. After complete combustion has taken place in the furnace, and the heated products have begun their flow towards the chimney, then the more they are deflected and turned from a straight course and made to impinge against heat absorbing surfaces in the boiler, the more heat will the gases give up, and, in consequence, the more water will be evaporated per pound of coal. This will, of course, interfere greatly with a natural or chimney draught. A forced draught, however, may be used with much greater economy and compel a flow of gases.

Position of heating surface—The relative values due to the different positions of heating surface have been determined by direct experiments with the following approximate results:

One square foot of heating surface placed at right angles to the current of heated gases so as to receive them by direct impact, was found to equal four square feet when placed diagonally to the current, or eight square feet when placed in a direction parallel to their flow. This shows the importance of securing a direct impact of heated gases against the absorbing surfaces of the boiler, whenever the designs can favor it. In all ordinary boiler construction this matter is wholly overlooked or disregarded, more attention having been paid to it in the designing of sectional boilers than, perhaps, any other class.

Heating surface of tubes and flues—The value of the heating surface of horizontal and vertical tubes has been greatly overrated. In almost all calculations the surface of tubes is counted in with that of the shell as being of equal value. A greater mistake can be hardly made. The results of experiments made to determine the value of tube heating surface shows it to be about $\frac{1}{10}$ that of fur-

nace heating surface. Mr. C. Wye Williams had an experimental boiler made in order to determine the exact values of heating surface in tubes in relation to their length. This boiler had twenty-five tubes, six feet long and two and a half inches in diameter.

The boiler was fitted with three water tight compartments; the first partition was placed at a distance of one foot from the front end, and a similar partition one foot from the rear end; thus making the two end compartments one foot long each, and the middle one four feet long. After having made suitable connections with a furnace at what we shall call the front end, it was observed that the water was brought to the boiling point in the first compartment (which was one foot long), after an interval of twenty-three minutes from the time of starting the fires; in the second or four feet compartment it required forty-eight minutes; and in the third or last compartment, fifty-nine minutes. The water having been brought to the boiling point, it was continued by careful and regular firing for three hours, with the following results:

First compartment, one foot long, two hundred and forty pounds water evaporated.

Second compartment, four feet long, an average evaporation of seventy pounds of water for each of the four feet in length.

Third compartment, one foot long, fifty pounds water evaporated.

Showing that the first foot of tube heating surface is the one of greatest value, and that long tubes add but little to the steaming capacity of a boiler.

In another experiment, it was shown that the first inch in length of tube was equal in efficiency to the next ten inches.

However valuable Mr. Williams' experiments may be in showing the popular error in estimating the value of

tube heating surface, it must not be supposed that it is next to worthless. The record of the ordinary horizontal tubular boiler, so largely used in this country, shows that tube surface has value, but to what extent, as compared with the shell, is not certainly known.

Figure 44 represents a cross section of a tube; from an inspection it will be seen that the most effective portion for heating is the top of the tube, which is represented by 1. As there is no perceptible amount of heat given off at the bottom of the tube, it is represented by 0; the sides of the tube are about half as effective as the top; then, adding together,

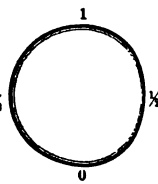


FIGURE 44.

$$\frac{1 + \frac{1}{2} + 0 + \frac{1}{2}}{4} = \frac{1}{2}$$

or, the effective heating surface of a tube, is approximately only one-half its circumference multiplied into its length.

The precise action of a column of heated gases in a flue is not known, but, from the fact that the gases escape at a temperature several times greater than the temperature of a compartment filled with water, as already described (page 193), we are led to infer that the central portion of the column of gases does not touch or give up any of its heat to the flue. This may be illustrated by the following diagram : *

700	600	500	400	300
700	700	700	700	700
700	700	700	700	700
700	600	500	400	300

FIGURE 45.

* Spon's Dictionary of Engineering

The several lines are supposed to represent the sections or strata of heated products passing through it, entering at a temperature of 700° and issuing at 540° . In this case the outer section, being next, and in contact with, the iron flue surface, will give out heat and be reduced, say to 300° , on arriving at the end of the flue.

Evaporation as modified by kind and extent of heating surface—The heating surface of a boiler is often used as a measure of its evaporative capacity, and as engines are usually rated by the horse power, boilers have had imposed upon them a similar rating, so that the capacity or power of a steam boiler is oftener rated by the horse power than by any other method, and this still further complicates matters, because the horse power of a boiler is usually made to correspond to that of the engine for which it is to furnish the steam, the power of which varies with the pressure of steam, and, as to whether it is a slide valve engine controlled by an ordinary governor, or an automatic cut off engine—the latter engine requiring a less quantity of water per horse power than the former. That the evaporative power of the boiler depends upon the heating surface there can be no doubt, for it is by this means alone that the heat of combustion is transferred to the water. This transfer may be either *direct*, as in the case of such portions of the boiler as are situated immediately around or above the fire; or, it may be *indirect*, as in the case of flues and tubes. The former is by direct radiation from the fire, the latter receives heat only by conduction. The relative values of the two kinds of heating surface are, for equal surfaces and similar conditions, about five to one in favor of direct heating.

The material of which the boiler is made and its thickness will have an effect on its evaporative power; the former only when perfectly clean, the latter at all times.

The quantities of heat transmitted through plates of metal, one inch thick, for one degree Fahrenheit difference of temperature, per hour, as determined by M. Peclet, are as follows:

Copper	555 units of heat.
Iron	225 units of heat.
Zinc	225 units of heat.
Tin	177 units of heat.
Lead	112 units of heat.

This, it should be observed, is for metals perfectly clean. M. Peclet found that all metals conduct heat about alike when their surfaces became dull. His experiments were with two boilers, one of which was made of copper and the other of cast iron. These were both exposed to an intense heat, and placed into the flame in such a manner that their surfaces became dulled; the evaporation was then carefully noted and was found to be about twenty pounds of water per square foot of surface per hour. In some experiments by Mr. James R. Napier, with small boilers of similar materials, and placed over a gas flame, the quantities of water evaporated were practically the same. Other experiments on a larger scale show that after a few days use there is practically no difference between the evaporation in an iron or in a copper boiler. This fact shows that the latter metal possesses no advantage over the former cheaper metal if allowed to get coated with soot. This practically confines the economical use of copper to the fire boxes of internally fired boilers, where, on account of the intense heat, it has no chance to become coated with soot. For the same reason there is no economy in the use of copper tubes in tubular boilers, unless kept perfectly clean.

In regard to thickness, it is known that the resistance to internal conduction is proportional to the distance the heat has to traverse, or, in other words, to the thickness

of the plate. The evaporative efficiency also depends, and inversely, on the difference of the temperatures between the two sides of the plate through which the heat is to pass. The number of heat units which will pass through a square foot of iron plate per hour may be found in the following manner:

From the temperature of the gases in the furnace and in contact with the boiler, subtract the temperature of the water in the boiler; divide this by the thickness of the plate, multiplied by .0096, which will give the quantity sought for. M. Peclet gives the decimal .0096 as the co-efficient of thermal resistance found by experiment. If for copper plates, then .0040 may be used instead.

In the preceding paragraph no account was taken of the resistance to external conduction on the one side, nor the resistance to the emission on the other. In order to arrive at the exact amount of heat which actually passes from the heated gases through the plates and taken up by the water, the total thermal resistance, both external and internal, must be taken into account.

In order to make any such calculation it will be necessary to know,

1. The resistance to the absorption of heat by the face of the plate next the heated gases.
2. The resistance to emission on the other side of the boiler plate which is in contact with the water.
3. The numerical value of the co-efficient of thermal resistance of the boiler plate.
4. The thickness of the boiler plate in inches.
5. The temperature of the heated gases, and
6. The temperature of the water in the boiler.

The quantity of heat transmitted may be found in this way:

Subtract the temperature of the water from that of the heated gases, and divide the remainder by a divisor

consisting of the co-efficient (3) multiplied by the thickness of the boiler plate, to which is to be added the resistance to absorption and the resistance to emission. This quotient will be the quantity of heat, in heat units, transmitted to the water.

The extent of heating surface in ordinary land boilers is dependent upon the length and diameter of the shell, the number and size of the tubes or flues.

In setting boilers in brick work it is customary to carry up the side walls parallel, and when a few inches below the water line of the boiler to set the bricks in by successive steps, as shown in figure 46. This portion of the circumfer-

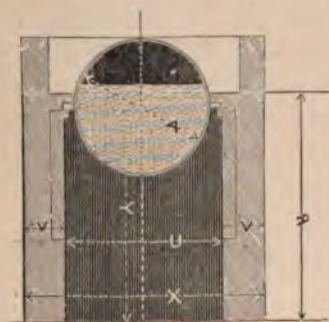


FIGURE 46.

ence multiplied into the length will give the heating surface of the shell. The next table gives the distance in feet for portions of circumferences, and all that is necessary to do in order to determine the heating surface of any shell is to know what portion of the circumference is used; find the number in the table where such fraction of circumference and diameter

of the boiler intersect, and multiply the figures so found by the length of the boiler in feet. This will give the heating surface of the shell in square feet.



TABLE LVI.
TABLE OF PARTIAL CIRCUMFERENCES OF BOILER SHELLS, FROM TWENTY-
FOUR TO SEVENTY-TWO INCHES IN DIAMETER.

DIAMETER OF BOILER.	PORTIONS OF CIRCUMFERENCE.				
	WHOLE.	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{1}{2}$	$\frac{1}{4}$
INCHES.	FEET.	FEET.	FEET.	FEET.	FEET.
24	6.28	4.71	4.19	3.93	3.14
26	6.81	5.11	4.54	4.25	3.40
28	7.33	5.50	4.89	4.58	3.67
30	7.85	5.89	5.24	4.91	3.93
32	8.38	6.28	5.59	5.24	4.19
34	8.90	6.68	5.93	5.56	4.45
36	9.42	7.07	6.28	5.89	4.71
38	9.95	7.46	6.63	6.22	4.97
40	10.47	7.85	6.98	6.55	5.24
42	11.00	8.25	7.33	6.87	5.50
44	11.52	8.64	7.68	7.20	5.76
46	12.04	9.03	8.03	7.53	6.02
48	12.57	9.42	8.38	7.85	6.28
50	13.09	9.82	8.73	8.18	6.55
52	13.61	10.21	9.08	8.51	6.81
54	14.14	10.60	9.42	8.84	7.07
56	14.66	11.00	9.77	9.16	7.33
58	15.18	11.39	10.12	9.49	7.59
60	15.71	11.78	10.47	9.82	7.85
62	16.23	12.17	10.82	10.14	8.12
64	16.76	12.57	11.17	10.47	8.38
66	17.28	12.96	11.52	10.80	8.64
68	17.80	13.35	11.87	11.13	8.90
70	18.33	13.74	12.22	11.45	9.16
72	18.85	14.14	12.57	11.78	9.43

In table LVII may be found the external heating surface in square feet for one lap welded wrought iron tube. The lengths given in the table will meet every ordinary requirement. If, however, the boiler requires tubes of a different length from those in the table, the heating surface given in the second column, multiplied into the length of such a tube, will give its area of heating surface in square feet.

TABLE LVII.

SHOWING THE EXTERNAL HEATING SURFACE IN ONE LAP WELDED BOILER TUBE OF THE FOLLOWING DIMENSIONS:

DIAMETER IN INCHES.	LENGTH IN FEET.						
	1	6	8	10	12	14	16
1	.262	1.57	2.09	2.62	3.14	3.66	4.19
1½	.327	1.96	2.62	3.27	3.92	4.58	5.24
1½	.393	2.36	3.14	3.93	4.75	5.50	6.28
1¾	.458	2.75	3.66	4.58	5.50	6.41	7.33
2	.524	3.14	4.19	5.24	6.29	7.33	8.38
2½	.589	3.53	4.71	5.89	7.07	8.25	9.42
2½	.655	3.93	5.24	6.55	7.86	9.17	10.47
2¾	.720	4.32	5.76	7.20	8.64	10.08	11.52
3	.785	4.71	6.28	7.85	9.42	10.99	12.57
3½	.850	5.10	6.80	8.50	10.20	11.90	13.61
3½	.916	5.50	7.33	9.16	10.99	12.82	14.66
3¾	.982	5.89	7.86	9.82	11.78	13.75	15.71
4	1.047	6.28	8.38	10.47	12.56	14.66	16.76
4½	1.178	7.07	9.42	11.78	14.14	16.49	18.85
5	1.309	7.85	10.47	13.09	15.71	18.33	20.94
6	1.570	9.42	12.56	15.70	18.84	21.98	25.13

The next table (LVIII) shows the external heating surface in one flue, from six to twenty-four inches diameter. In case the length in feet given in the table does not corre-

spond to the length of the boiler, any column containing a fractional length may be used as a convenient multiplier, or the figures in two columns may be added together, thus: Required the heating surface in one flue, seventeen inches diameter, twenty-six feet long? This length is not contained in the table, but by adding together the figures in columns twelve and fourteen feet, thus, $\frac{53.41}{62.31}$ $\frac{115.72}{115.72}$ the correct amount is given.

TABLE LVIII.

SHOWING THE EXTERNAL HEATING SURFACE IN ONE FLUE OF THE FOLLOWING DIMENSIONS.

DIAMETER IN INCHES	LENGTH IN FEET.						
	1	12	14	16	18	20	22
6	1.5708	18.85	21.99	25.13	28.27	31.42	34.56
7	1.8326	21.99	25.66	29.32	32.99	36.65	40.32
8	2.0944	25.13	29.32	33.51	37.70	41.89	46.08
9	2.3562	28.27	32.99	37.70	42.41	47.12	51.84
10	2.6180	31.42	36.65	41.89	47.12	52.36	57.60
11	2.8798	34.56	40.32	46.08	51.84	57.60	63.36
12	3.1416	37.70	43.98	50.27	56.55	62.83	69.12
13	3.4034	40.84	47.65	54.45	61.26	68.07	74.87
14	3.6652	43.98	51.31	58.64	65.97	73.30	80.63
15	3.9270	47.12	54.98	62.83	70.69	78.54	86.39
16	4.1888	50.27	58.64	67.02	75.40	83.78	92.15
17	4.4506	53.41	62.31	71.21	80.11	89.01	97.91
18	4.7124	56.55	65.97	75.40	84.82	94.25	103.67
19	4.9742	59.69	69.64	79.59	89.54	99.48	109.43
20	5.2360	62.83	73.30	83.78	94.25	104.72	115.19
21	5.4978	65.97	76.97	87.96	98.96	109.96	120.95
22	5.7596	69.24	80.77	92.31	103.85	115.39	126.93
23	6.0214	72.26	84.30	96.34	108.39	120.43	132.47
24	6.2832	75.40	87.96	100.53	113.10	125.66	138.23

Grate area—From results of experiments made personally, and from an inspection of experiments made by others, the writer has about come to the conclusion that there is no such thing as a fixed relation between grate area and heating surface, suited even to average conditions.

Among the things to be taken into account, in fixing the grate area, are,

The quantity of water to be evaporated.

The kind and quality of fuel to be used.

The details of the boiler and setting.

Whether a natural or forced draft is to be employed.

Whether the water used will form scale.

The ability and faithfulness of the fireman.

The theoretical grate area may be fixed when the first three of the above conditions are known; subject, however, to the modifying influences of the other three.

There are several empirical rules for fixing the grate area, among which may be mentioned that of Armstrong, whose rule it was, to allow a square foot of grate area for each cubic foot of water to be evaporated per hour, and one square yard of heating surface per horse power, for ordinary coal. The grate area might be lessened to three-fourths of a square foot for good coal, and to half a square foot for the best coal.

Another rule is, to divide the number of pounds of water to be evaporated per hour, from and at 212° Fahrenheit, by the following numbers, which will give the area in square feet :

If for cylinder boilers, by.....	75
For flue boilers, by.....	77
For horizontal tubular boilers, by.....	78
For vertical tubular boilers, by.....	79
For locomotive and portable boilers.....	80

The amount of coal burned per hour, per square foot of grate surface, is, for stationary boilers with natural draft,

Bituminous coal.....	10 to 25 pounds.
Semi anthracite.....	10 to 20 pounds.
Hard anthracite.....	8 to 16 pounds.

When a forced draft is used, these figures may be doubled, if necessary, in which case thicker fires should be used, and will require greater care in firing, that the heat may not be wasted by the strong draft.

The rate of combustion per hour per square foot of grate being known, the area of grate surface may be approximately fixed as follows:

For externally fired boilers, with moderate draft, .08 sq. ft. per lb. of coal.
For externally fired boilers, with quick draft..... .06 sq. ft. per lb. of coal.
For externally fired boilers, with forced draft..... .04 sq. ft. per lb. of coal.
For internally fired boilers, with quick draft..... .03 sq. ft. per lb. of coal.
For internally fired boilers, with forced draft..... .02 sq. ft. per lb. of coal.
For locomotive boilers..... .01 sq. ft. per lb. of coal.

These numbers are nearly the reciprocals of the number of pounds of coal burned per hour per square foot of grate.

A common method of fixing the area of grate surface is to build the furnace walls from four to four and a half inches distant from the side of the boiler, the length of the grate varying from forty-two inches to six feet. Table LXVIII gives the sizes used by the writer in ordinary boiler settings; the area is larger than is necessary for good coal and for a quick draft. The best way to reduce it is to lay a course of brick work along each side wall until the area is such that the most economical rate of combustion is secured. In this way the area of grate may be suited to the local conditions which affect any particular case, but will furnish no reliable data for another section of the country, or one in which the fuel, draft and attention to firing may be different.

Evaporation—In order to evaporate a given quantity of water in a given time two things are to be taken into

account—first, the area of heating surface, and, second, the average rate of transmission of heat per square foot of surface. Evaporation is commonly reckoned by the number of pounds of water which one pound of net combustible will convert into steam at atmospheric pressure, the feed water being supplied and evaporated at 212° Fahr. Other things being equal, it would be expected that the boiler which presents the greater amount of heating surface would evaporate the greatest quantity of water; practically, the rate of evaporation varies considerably for different parts of the same boiler, the portion nearest the fire evaporating the most water in any given time. The cleanliness of the boiler, both external and internal, has much to do with the evaporation. If a coating of soot accumulates along the lower side of the boiler, or in the flues, it will interfere with the transfer of heat, because soot is a bad conductor. If a coating of scale accumulates inside of the boiler it will also interfere with the rapid transmission of heat, for the reason that scale, like soot, is a bad conductor, and coming in between the iron and the water prevents the latter from receiving the heat transmitted through the boiler plates. Neither of these can be taken into account in determining the theoretical evaporating capacity of a boiler, because of the constantly varying quantities of these two non-conductors.

It has been demonstrated, experimentally, that one pound of good coal will evaporate, under favorable conditions, from nine to twelve pounds of water from and at 212° Fahrenheit. The rate of evaporation, per square foot of heating surface, will vary from 1.5 to 9 pounds. The actual rate of evaporation, per square foot of heating surface, for the different kinds of boilers, varies within such wide limits as to practically render worthless the formulas bearing on this subject.



The following tables (LIX and LX) may be of use, however, in approximating equivalent evaporation for different temperatures of feed water between 32° and 212° Fahrenheit:

TABLE LIX.
PROPERTIES OF SATURATED STEAM.

PRESSURE.		TEMPERATURE IN FAHRENHEIT DEGREES.	VOLUME.		LATENT HEAT IN FAHRENHEIT DEGREES.	TOTAL HEAT REQUIRED TO GENERATE ONE POUND OF STEAM FROM WATER AT 32° FAHRENHEIT, UNDER CONSTANT PRESSURE. IN HEAT UNITS.
BY STEAM GAUGE.	TOTAL.		COM- PARED WITH WATER.	CUBIC FEET OF STEAM FROM ONE POUND OF WATER.		
0	15	212.0	1642	26.36	965.2	1146.1
5	20	228.0	1229	19.72	952.8	1150.9
10	25	240.1	996	15.99	945.3	1154.6
15	30	250.4	838	13.46	937.9	1157.8
20	35	259.3	726	11.65	931.6	1160.5
25	40	267.3	640	10.27	926.0	1162.9
30	45	274.4	572	9.18	920.9	1165.1
35	50	281.0	518	8.31	916.3	1167.1
40	55	287.1	474	7.61	912.0	1169.0
45	60	292.7	437	7.01	908.0	1170.7
50	65	298.0	405	6.49	904.2	1172.3
55	70	302.9	378	6.07	900.8	1173.8
60	75	307.5	353	5.68	897.5	1175.2
65	80	312.0	333	5.35	894.3	1176.5
70	85	316.1	314	5.05	891.4	1177.9
75	90	320.2	298	4.79	888.5	1179.1
80	95	324.1	283	4.55	885.8	1180.3
85	100	327.9	270	4.33	883.1	1181.4
90	105	331.3	257	4.14	880.7	1182.4
95	110	334.6	247	3.97	878.3	1183.5
100	115	338.0	237	3.80	875.9	1184.5

TABLE LIX—CONTINUED.

PRESSURE.		TEMPERATURE IN FAHRENHEIT DEGREES.	VOLUME.		LATENT HEAT IN FAHRENHEIT DEGREES.	TOTAL HEAT REQUIRED TO GENERATE ONE POUND OF STEAM FROM WATER AT 32° FAHRENHEIT, UNDER CONSTANT PRESSURE. IN HEAT UNITS.
BY STEAM GAUGE.	TOTAL.		COM-PARED WITH WATER.	CUBIC FEET OF STEAM FROM ONE POUND OF WATER.		
105	120	341.1	227	3.65	873.7	1185.4
110	125	344.2	219	3.51	871.5	1186.4
115	130	347.2	211	3.38	869.4	1187.3
120	135	350.1	203	2.27	867.4	1188.2
125	140	352.9	197	3.16	865.4	1189.0
130	145	355.6	190	3.06	863.5	1189.9
135	150	358.3	184	2.96	861.5	1190.7
140	155	361.0	179	2.87	859.7	1191.5
145	160	363.4	174	2.79	857.9	1192.2
150	165	366.0	169	2.71	856.2	1192.9
155	170	368.2	164	2.63	854.5	1193.7
160	175	370.8	159	2.56	852.9	1194.4
165	180	372.9	155	2.49	851.3	1195.1
170	185	375.3	151	2.43	849.6	1195.8
175	190	377.5	148	2.37	848.0	1196.5
180	195	379.7	144	2.31	846.5	1197.2

The above table gives the values of all the properties of saturated steam usually required in any calculations connected with steam boilers; and by the aid of the next table, taken from Professor Rankine's Treatise on the Steam Engine, the equivalent evaporation from and at 212° may be easily determined, the actual number of pounds of water evaporated per pound of coal and the temperature of the feed water being known.

TABLE LX.
FACTORS OF EVAPORATION.

TEMPERATURE OF THE STEAM.	TEMPERATURE OF THE FEED WATER.										
	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
212°	1.19	1.17	1.15	1.13	1.11	1.10	1.08	1.06	1.04	1.02	1.00
230°	1.20	1.18	1.16	1.14	1.12	1.10	1.08	1.06	1.04	1.02	1.01
248°	1.20	1.18	1.16	1.14	1.13	1.11	1.09	1.07	1.05	1.03	1.01
266°	1.21	1.19	1.17	1.15	1.13	1.11	1.09	1.07	1.06	1.04	1.02
284°	1.21	1.20	1.18	1.16	1.14	1.12	1.10	1.08	1.06	1.04	1.02
302°	1.22	1.20	1.18	1.16	1.14	1.12	1.11	1.09	1.07	1.05	1.03
320°	1.22	1.21	1.19	1.17	1.15	1.13	1.11	1.09	1.07	1.05	1.03
338°	1.23	1.21	1.19	1.17	1.15	1.14	1.12	1.10	1.08	1.06	1.04
356°	1.23	1.22	1.20	1.18	1.16	1.14	1.12	1.10	1.08	1.06	1.04
374°	1.24	1.22	1.20	1.18	1.17	1.15	1.13	1.11	1.09	1.07	1.05
392°	1.24	1.23	1.21	1.19	1.17	1.15	1.13	1.11	1.09	1.07	1.06
410°	1.25	1.23	1.22	1.20	1.18	1.16	1.14	1.12	1.10	1.08	1.06

The use of the above table will be illustrated in the solution of the following example :

A boiler evaporates nine pounds of water per pound of coal, the feed water being 68° and the pressure of steam one hundred pounds per square inch ; what is the equivalent evaporation from and at 212° ?

The temperature of steam corresponding to one hundred pounds pressure, as seen from table LIX, is 338°. The factor of evaporation corresponding to this temperature, the feed entering the boiler at 68°, according to table LX is 1.19, which, multiplied by the pounds of water evaporated, will be $1.19 \times 9 = 10.71$ pounds of water per pound of coal.

If any particular type of boiler had a regular rate of evaporation per square foot of heating surface, a series of tables might easily be calculated by which the probable

performance of a boiler might be given in advance of its manufacture, or if the rate of the transmission of the heat through the plates to the water was anything like constant, it might prove a useful factor in boiler calculations, but, unfortunately, neither of these have any practical value except for the first few days the boiler is used after completion.

The following table and rule from Northcott's Theory and Action of the Steam Engine shows the approximate mean rates of transmission of heat per square foot of heating surface per hour, corresponding with various degrees of efficiency, and for the principal classes of boilers used in practice:

TABLE LXI.
SHOWING MEAN RATE OF TRANSMISSION OF HEAT THROUGH BOILER PLATES.

EFFICIENCY.	INTERNALLY FIRED BOILERS OF THE CORNISH AND LANCASHIRE TYPES.		GOOD TUBULAR BOILERS WITH BRISK COMBUSTION.	LOCOMOTIVE BOILERS WITH STRONG STEAM BLAST AND RAPID COMBUSTION.
	SLOW COMBUSTION AND SLUGGISH GAS AND WATER CIRCULATION.	WITH GOOD CHIMNEY DRAFT AND CIRCULATING TUBES IN FLUES.		
	2,200° FAHR.	2,600° FAHR.	3,000° FAHR.	3,500° FAHR.
.50	12,000	15,000	20,000	30,000
.55	9,000	12,000	16,000	23,000
.60	6,000	9,000	12,000	17,000
.65	4,500	7,000	9,500	13,500
.70	3,000	5,000	7,000	10,000
.75	2,300	4,000	5,500	8,000
.80	1,500	3,000	4,000	6,000
.85	.....	.....	3,300	4,800
.90	.....	.....	2,500	3,500

If we wish to know in advance what area of heating surface would be required in a tubular boiler to carry 100 pounds of steam, and evaporate 60 cubic feet of water per hour, we first reduce the cubic feet of water to pounds, thus: $62.5 \times 60 = 3,750$ pounds of water to be converted into steam. By referring to table LIX, we find the total heat required to generate one pound of steam from water at 32° Fahrenheit, in heat units, to be 1184.5; then, $1184.5 \times 3750 = 4,441,875$. If the efficiency of the furnace be .70 we find 7,000 in table LXI to be the mean rate of transmission; then $\frac{4,441,875}{7,000} = 635$ square feet of heating surface required. This would require a tubular boiler, say 48 inches diameter \times 14 feet long, with 50 three-inch tubes.

RULE—To ascertain the area of heating surface of a proposed steam generator, multiply the quantity of water to be evaporated in pounds by the heat expended per pound of steam. This quantity divided by the mean rate of transmission, as given in table LXI, for the required degree of efficiency, gives the area of heating surface in square feet.

Horse power of boilers—Perhaps no more unsatisfactory unit has ever been employed than that of horse power as a unit of measurement for steam boilers; and so long as it is applied to engines it will be, in all probability, applied to boilers. This term is in such general use among builders and users, alike, that it would be extremely difficult to substitute another rating to take its place. It has been proposed to rate boilers by their extent of heating surface. There is no particular objection to this, if heating surface was a thing of specific value. Boilers not only vary among themselves in the value of heating surface, but it is not of equal value in the same boiler. It has also been proposed to rate boilers by the amount of water evaporated into dry

steam per hour. This is not altogether satisfactory, for evaporation is dependent upon other things than the boiler itself: for example the construction of the furnace or boiler setting will have a marked influence on the rate of evaporation. The volume and force of the draft, together with the arrangement and size of the grate furnace, will also have much to do with the evaporation. The conditions of the heat absorbing surfaces, whether covered with scale on the inside or soot on the outside, will affect the rate of evaporation in a marked degree. The kind and quality of fuel used, the pressure of steam, and the temperature of the feed water are all hindrances.

Boilers are usually made to furnish steam for an engine. It is the horse power of the engine which fixes the size of the boiler. If it is a high grade, automatic cut off engine, the quantity of water required will vary from one-third to one-half a cubic foot of water per hour per horse power. If an ordinary slide valve engine, one cubic foot of water per hour per horse power; and there are direct acting pumping engines which require as much as two cubic feet of water per hour per horse power.

Neglecting the latter, which of the others is to be taken as the standard of evaporation?

All things considered, perhaps the best practice is to allow one cubic foot of water per hour per horse power. This will be ample for ordinary slide valve engines, and will furnish a surplus of power often needed in the case of cut off engines.

How much heating surface shall be allowed for this evaporation for different kinds of boilers?

There is a rule of thumb, which has long been in use and is still used (within very slight variations) in almost every boiler shop in the country, and is as follows:

SQUARE FEET OF HEATING SURFACE PER HORSE POWER:

Cylinder boilers.....	9
Flue boilers.....	12
Tubular boilers.....	15

Watts' rule for the horse power of boilers—One square foot of grate surface, one square yard of heating surface, one-half a square yard of water surface, represent one horse power; and these dimensions will suffice to evaporate one cubic foot of water per hour.

The one square yard of heating surface has no reference to the ordinary flue or tubular boilers as now constructed. It was intended for the Waggon boiler, now obsolete.

Another rule for tubular boilers is,

Multiply the number of square yards of heating surface by the area of grate surface in square feet, and extract the square root, multiply this by 1.8 = H. P. of the boiler.

Another rule for internally fired boilers of the Cornish and Lancashire types is,

Multiply together the square yards of heating surface in the boiler, and the grate area in square feet, and extract the square root = H. P. of boiler.

Another rule for cylinder boilers is,

Divide the sectional area of the boiler by 6 = H. P. of boiler.

Another rule for steam boilers, where the rate of evaporation is assumed, and thus fixing the area of grate surface in square feet for any given boiler, the heating surface in square feet may be found as follows :

Grate surface x 11 = heating surface for cylinder boilers.
Grate surface x 17 = heating surface for flue boilers.
Grate surface x 24 = heating surface for vertical tubular boilers.
Grate surface x 26 = heating surface for portable boilers.
Grate surface x 30 = heating surface for locomotive boilers.

Professor R. H. Thurston estimates that for the *best* steam engines (those using high pressures and working expansively), the quantity of water required to be evaporated per hour, per horse power, is equal to the constant 150, divided by the square root of the pressure. The horse power is to be understood as that furnished by the indicator. The quantity of water required for the best Corliss engines, for example, using steam at one hundred pounds pressure, would be ascertained by this formula, as follows: Square root of 100 = 10; then, $\frac{150}{10} = 15$ pounds of water required per hour, per indicated horse power, or about $\frac{1}{4}$ of one cubic foot. This, it should be understood, takes no account whatever of the losses incident to the generation of steam, but shows what the demand of the engine is upon the boiler. For *good* engines he increases the constant to 200. This would give for the same pressure twenty pounds of water, which accords closely with good average practice for high grade engines.

By carrying this still further a constant of 350 might be employed for slide valve engines. This class of engines use steam of lower initial pressure, and with less economy than those above referred to. The usual point of cutting off is two-thirds stroke, which allows but one-third for expansion. If an initial pressure on the piston be assumed to be fifty pounds, or to get rid of a fraction we will say forty-nine pounds, we have: Square root of 49 = 7; then, $\frac{350}{7} = 50$ pounds of water required per hour, per horse power, or nearly five-sixths of a cubic foot.

Circulation—The power of a boiler is more dependent upon a proper circulation of the water in it than is generally believed, or more attention would be paid to it in boiler design. When heat is applied to the shell of a boiler a movement takes place in the water, and there is a motion of the particles, in which the heated ones below change

places with the cooler particles above. This always takes place in any vessel when heated from below, and is the particular movement known as convection. The movement of these particles of the water upward not being the same throughout the boiler, causes a movement of the whole body of the water by producing upward currents in one portion and downward currents in another; it is this movement of the water which is to be understood as circulation, and not the movement of the heated particles changing places among themselves in the water. It is by these two combined movements, convection and circulation, that heat is diffused throughout the whole body of water and its temperature raised to a point where ebullition begins, accompanied by evaporation.

Water is not a good conductor of heat; in fact, it is a very bad one. A familiar laboratory experiment to prove this is take a long glass tube closed at the lower end, fill it with water, incline it at a suitable angle, and place a spirit lamp under the upper end; in this way the water in the upper portion of the tube may be made to boil, while the water at the lower end will have scarcely risen in temperature. But if the heat be applied to the bottom of the tube, the contents will soon



FIGURE 47.



FIGURE 48.

become heated, the bottom particles first; these expand because of their increased temperature, and being somewhat lighter than the other particles, are forced upwards through the superior density of the colder water above. This process of convection is continually increased until rapid circulation is established, which will continue so long as the conditions favorable to it remain.

Cylinder boilers are most favorable to circulation because of the entire absence of tubes or flues, which always tend to impede it. If the temperature were uniform throughout the whole length of the boiler, the ebullition

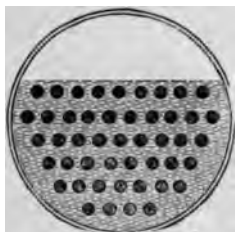


FIGURE 49.

would also be going on the whole length, but as the boiler is heated at one end the difference in temperature between the two ends may vary from $3,000^{\circ}$ at the furnace to 800° at the end where the gases pass into the chimney; consequently the water at the furnace end of the boiler will be more highly heated than at the other end. It is

to be expected, and actually occurs, that the ebullition is more violent at this portion than any other in the boiler. It has the effect to raise the water level somewhat, and thus causes a surface flow from the front to the back end of boiler, thence downward to the bottom and along the shell to the furnace. This longitudinal circulation is favorable to rapid evaporation.

A very common form of boiler is shown in figure 47. When heat is applied directly underneath, the flow of water will be upward between the flues and down the sides. If more heat be applied to the sides than underneath, the current of water is changed, and the downward flow is through the center and between the flues. Circulation is most difficult in tubular boilers when the tubes are arranged zig-zag, as shown in figure 49. The upward circulation is interfered with by the water alternately impinging against the tubes, and thus changing its course between each horizontal row. A better arrangement is shown in figure 48, in which the tubes are placed in vertical rows, and still better, when the middle row of tubes are taken out, as

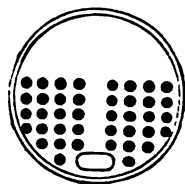


FIGURE 50.

shown in figure 50. The circulation is then analogous to that described for flue boilers. The following abstract from a paper on the Circulation of Water in Steam Boilers,* is from the pen of Mr. Robert Wilson:

"When, for the purpose of increasing the extent and efficiency of the heating surface, the large body of water is divided into smaller sections, connected by water passages, another movement of the body of water is usually set up. In a Galloway boiler, for instance (see figure 51), there is, besides the ebullition, a movement of the water in some of the tapered tubes, which is due to the difference in the weight of two columns of water of the same height, but of different density, the lighter column being inside the tube and the heavier outside. In the tubes just behind the bridge, which are exposed to the highest temperature, the water is more highly heated and more dilated than that in the water spaces at the sides of the boiler. The unbalanced weight of the latter causes the water in the tubes to rise, and so a movement is set up, which becomes a continuous circulation so long as the necessary conditions exist. This upward motion of the whole body of water in the tube we may call *draught* circulation, which goes on at the same time as and independently of the ebullition. It is this draught circulation that carries away the solid matters which are precipitated by the ebullition. Where there is simply ebullition, the heating surfaces become coated with incrustation, where the nature of the feed water is such as to favor its formation. In Galloway boilers this is shown by the thickness of the incrustation in the tubes, increasing with the diminution of the draught circulation as we recede from the furnace.



FIGURE 51.

* From Engineering.

"The great accumulation of incrustation at the back end of these boilers is also in some measure due to the "tidal" circulation depositing the solid matters here which have been precipitated nearer the furnaces. When the "draught" circulation in the Galloway tube near the furnace is arrested by, for instance, a Hopkinson safety valve float swaying a few inches above the mouth of the tubes, incrustation rapidly forms, in spite of the ebullition that goes on, and which is usually but wrongly credited with the merit of preventing scale from accumulating.

"The shape of the tapered tube, with its greatest diameter at the top, whilst it favors the ebullition and the free escape of the steam particles as they are formed on the sides of the tube, at the same time reduces the rapidity of the draught circulation as the square of the increase of diameter. Now, as the carrying away of the solid matter, which is deposited by the evaporation of the water, is mainly dependent upon the efficiency of the draught circulation, it follows that by reducing the draught efficiency the taper of the tube favors the formation and accumulation of incrustation, which impairs the efficiency of the heating surface of the tube. It would, therefore, appear that in some cases the tapering may actually tend to defeat the purpose for which the tube is introduced. It has hitherto been considered that a vertical taper tube is theoretically better calculated to promote the generation of steam than a vertical straight tube. But as the theory on which this conclusion is based does not take account of all the processes involved, its correctness is more than questionable. Of course, the practical constructive advantages and facility for cleaning afforded by the taper shape must be taken into consideration, as well as the amount of taper in proportion to the length of the tube, the position of the tube in the boiler, and the nature of the feed water, in

determining whether a taper tube is better than a straight one in any given case.

"In some cases we might, with advantages, even reverse the taper in order to promote the draught circulation, upon which is dependent, in some measure, the warming of the large body of dead water in boilers without external flues and having the fire grate above the shell bottom. The warming of this dead water is also slowly effected by the tidal circulation and by the diffusion downwards of the heat from the furnace, which takes place when the heat is imparted to the body of water more rapidly than it can be carried away by the convection upwards, which first takes place.

"When there are many vertical tubes, as in a Galloway boiler, it will depend upon the relative areas of the side water spaces and of the tubes, the temperature of the gases in contact with the vertical and horizontal tubes at any given moment, and upon the condition of the heating surface, whether there will be an upward or downward current in the tubes near the back end of the boiler."

CHAPTER X.

EXTERNALLY FIRED BOILERS.

Cylinder Boilers—Safety and Economy of—Vertical Cylinder Boiler—The French or Elephant Boiler—Two-flue Boilers—Five-flue Boilers—Boilers fitted with six-inch lap Welded Flues—Test of a Flue Boiler—Tubular Boilers—Arrangement and number of Tubes—Proportions for Shells—Grate Area—Coal required per hour—Tube Area—Evaporative Power of Tubular Boilers—Compound Tubular Boiler.

Externally fired boilers—The simplest form of a boiler is a plain cylinder set in brick work. This type of boiler is largely used in sections of the country where coal is cheap, or in the lumber regions, where sawdust and slabs are used as fuel. In many cases where fuel is abundant and cheap, the feed water hard and apt to form a troublesome scale, cylinder boilers recommend themselves as being at once easily managed, easily cleaned, offering, with the exception of the sphere, the strongest possible form to resist bursting, and affording the readiest facility for examination and repairs; and, for a given weight or efficiency of heating surface, the lowest priced boiler that is now in the market.

These boilers steam well, and prime less than any other form. In mining and lumber regions they are especial favorites, and it would be difficult to displace them, especially if the feed water is impure. They are also extensively used at blast furnaces, and less so, perhaps, in rolling mills.

An argument used against externally fired boilers is, that the plates immediately over the furnace are liable to

become overheated either by too hard firing or by the accumulation of scale in the boiler; the pressure being internal, the tendency to rupture being that of bursting. The plates are none too strong to begin with, and being further weakened by overheating they become dangerous in the extreme, and are thus liable to explode at any time when overworked.

There is much of a showing of truth in the statement, but fortunately it has not been verified in actual experience. That explosions of externally fired boilers brought about by the overheating of plates has occurred, is not denied. Whether the disastrous effects are more or less than that occasioned by the collapse of the main flue of an internally fired boiler does not concern us. If the question be resolved to that of absolute, and not relative safety, and it were asked whether any form of riveted boiler, either externally or internally fired, could be made absolutely safe, there could be but one answer, and that—no. It becomes then a matter of relative safety. This can be secured only by a careful selection of plates and the best proportions and workmanship. The writer has gone over his ground very carefully, and is of the opinion that, if iron is used having a tensile strength of not less than 50,000 pounds, or steel having a tensile strength of 60,000 or 65,000 pounds, the longitudinal seams double riveted, all the rivet holes carefully matching each other, and the workmanship good throughout, that the pressures given in tables XLVII and XLIX are none too high; and if the boiler is properly fired and taken care of, there need be no apprehensions as to its safety.

Cylinder boilers commonly range between thirty and forty-two inches in diameter, and in length from eight to twelve diameters. The great length given this type of boiler over those fitted with flues or tubes is to present a greater surface for the absorption of the heat from the

gases. These boilers are usually set in "batteries" of from two to six. The latter is too many, the former making a far better arrangement, and will also permit cleaning or repairs to be made without interfering with the others in use.

The usual mode of setting these boilers is to have them suspended in the furnace. For this purpose special forgings or pieces of T iron are riveted to the upper portion of the shell, one-fourth the length of the boiler from each end, where two suspension bolts are to be used. If more than two, they are so disposed as to have each bolt bear its proportion of weight. These suspension bolts are carried up between a pair of wrought iron beams or castings, which span the furnace, and adjusted by means of nuts and washers to the required level. The writer does not, in general, recommend more than two points of suspension, on account of the distortion of the boiler, caused by the unequal heating of the lower and upper portions of the shell.

An argument used against cylinder boilers is that, they are not economical in the use of fuel. There is much of truth in this assertion; but less attention is, as a general thing, paid to the setting of cylinder boilers, and which will, in a measure, account for their lack of economy. As a rule, the furnaces are too large, as is also the space under the boiler and the openings leading to the chimney; the draft being regulated at the ash pit door in the fire room. This is far from the best way of getting the greatest evaporation in a cylinder boiler. There should be a wall at the back end of the boiler similar to that shown in the engraving of tubular and flue boiler settings. Such a wall will compel a flow of gases from the furnace to keep in close contact with the shell of the boiler. Immediately back of the end of the boiler should be placed a damper, and should, by means of a rope or other device, be so

arranged that it could be opened or closed at will. This damper should be so adjusted that the flow of gases from the furnace shall only be that necessary to supply the burning fuel with oxygen. This will be found to yield better results than keeping the damper wide open and regulating the supply of air through the ash pit doors.

The following description, from Engineering, of the cylinder boilers of the Cambria Iron Company, Johnstown, Pa., by Mr. A. L. Holley, may be of interest to many: "The furnace is supplied with steam by eight cylinder boilers, each sixty feet long and forty-eight inches in diameter. The boilers are set in pairs, each connected below on each outside sheet by short cross boilers, thirty inches in diameter and six feet long, with sixteen-inch connections. The gases* are admitted at the ends of the boilers into combustion chambers, similar to those in the Player stoves, and thence they pass through flues under the boilers.

"To provide for emergencies a firing grate, six feet square, is placed twenty feet from the ends of the boilers. Each pair of boilers is hung on wrought iron turned arches supported by side walls. The boilers are suspended by bolts resting on spiral springs, and are perfectly free between the walls; there is no trouble resulting from expansion and contraction. The cross boilers have each a branch, ten inches in diameter, extending through the side walls, with four-inch spaces all around them, the space being covered with loose plates of iron. The branches receive the feed water, and also serve to connect the blow off, which is inserted in the neck far enough to be bent, so as to reach the lowest point of the cross boiler. This arrangement enables each cross boiler to be blown off separately. The feed pipe is ten inches in diameter, having connections with each cross boiler. The boilers are so

* The gases from the blast furnace, being principally carbonic oxide gas, may be used as fuel. B.

arranged that any pair can be cut off for any purpose without interfering with the working of the furnace."

Vertical cylinder boilers—Messrs. Douglas & Sons, Philadelphia, Pa., have put in several of their patent vertical cylinders in that city, and at Youngstown, Ohio, on a plan which may be new to many of the readers, but which promises, from what the writer is able to learn, to be a success. Figure 52 shows a boiler arranged to receive the waste heat from a puddling furnace. The boiler itself is a plain cylindrical vertical boiler, at a short distance below the water level, say twelve inches, a head is inserted, and another cylinder added of such diameter as may be needed for the steam.

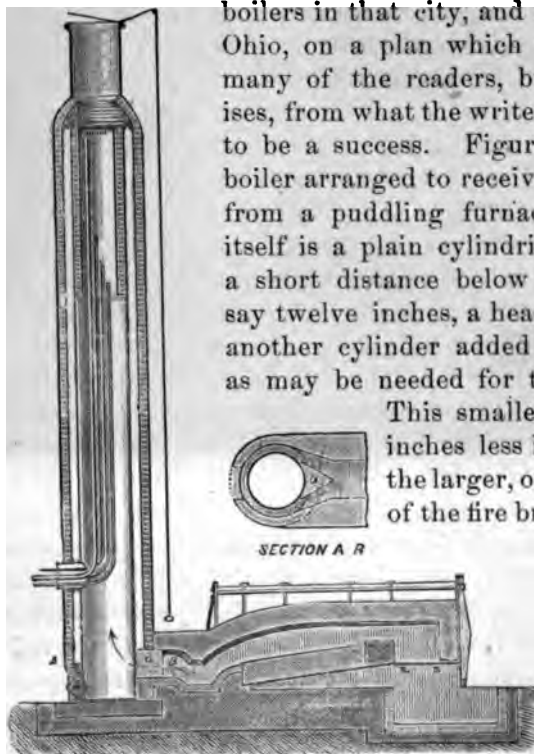


FIGURE 52.

This smaller cylinder is twelve inches less in diameter than the larger, or twice the diameter of the fire brick built around it. The steam is drawn off as shown in the engraving. The object of this arrangement is to prevent the steam from becoming too dry, and thus furnish the engines perfectly dry.

An opening is made in the side of the boiler at a convenient distance from the bottom and a special fitting is used to draw off the steam.

attached, through which the gauge cock pipes pass. These are, as usual, three in number. The first runs up to within six feet, the second to seven feet and the third to within eight feet of the top of the boiler. The steam pipe is also attached to this fitting, and passes up to within six inches of the top.

The boiler is encased in a sheet iron stack large enough to be lined with four and a half inch brick wall, and leaves a five inch fire space between boiler and brick. The man hole is at the bottom of the boiler, and the blow off valve connected to the lower head of boiler. By this method of setting it is possible to work cold water into the boiler without injury, by introducing it below the heating surface. Scales or dirt do not adhere to the sides of the boiler, but fall to the bottom, from which they are easily removed.

The French boiler—This is also called the Elephant boiler. It is extensively used in France and on the continent of Europe. The writer is not aware that any are in

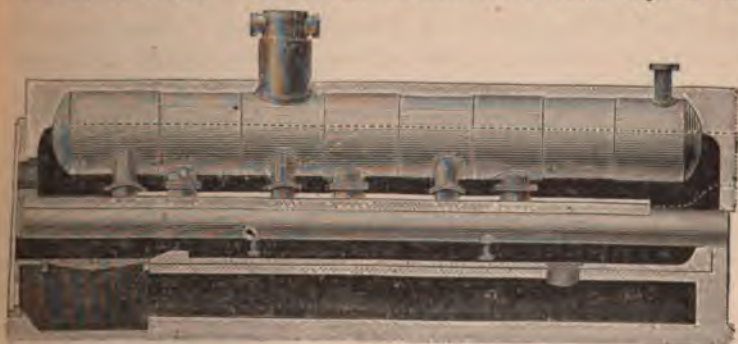


FIGURE 53.

use in this country. This boiler is an assemblage of two or three smaller cylinder boilers and a large shell into one structure. It will be observed, by referring to figures 53 and 54, that the lower cylinders or tubes are filled with water and almost wholly surrounded by heated gases. These lower



FIGURE 51.

cylinders have suitable connections to permit a free and rapid circulation of water between them and the larger cylinder above. The number of lower cylinders varies from one to three, but commonly two. The particular boiler illustrated here is a representation of the one used in the famous experiments at Mulhouse, the principal dimensions being as follows: The main body of this boiler* is 20 feet $6\frac{3}{4}$ inches long by 3 feet 8.9 inches in diameter, and is made of half inch plates, except the ends, which are 0.55 inch thick. The three lower cylinders are 19.7 inches in diameter by 32 feet $9\frac{1}{4}$ inches long, and are made of 0.39 inch plates, while each communicates with the main body of the boiler by three connecting tubes. The grate is 4 feet $9\frac{1}{10}$ inches in width by 4 feet $9\frac{3}{10}$ inches long. This includes 6.7 inches taken up by the bearings of the bars. Taking the effective length of the grate, 4 feet $2\frac{6}{10}$ inches, the area is 20.05 square feet. The heating surface of the boilers is 607.6 square feet, divided as follows:

	SQUARE FEET.
Surface exposed by main body of boiler.....	199.48
Surface exposed by three lower cylinders.....	385.68
Surface exposed by nine connecting pipes.....	22.44
	<hr/> 607.60

The setting of this boiler is arranged as shown in the engraving, so that the products of combustion act first on the surfaces of the three lower cylinders, then return to the front end, along one side of the main cylinder, and finally pass to the chimney along the other side. This boiler was also provided with a "butterfly" damper, worked by a lever provided with a sector. The areas of

*Engineering, volume 21.

Opening of the damper corresponding to each notch of the sector was measured and found to be as follows:

Number of notch.....	1	2	3	4	5	6	7
Area in square feet for opening.....	0.325	0.394	0.533	0.812	1.161	1.500	1.885

The boiler was also supplied with the usual fittings.

During the experiments a record was kept of the coal and water consumption, and observations were made of the temperatures of the gases entering the chimney, of the analysis of these gases, and of the quantity of water taken off, in suspension, by the steam. The following table gives the results obtained with both light and heavy firing:

TABLE LXII.

GIVING AN ABSTRACT OF RESULTS OBTAINED BY EXPERIMENTAL TESTS
MADE WITH THE FRENCH, OR ELEPHANT BOILER,
DESCRIBED ON PAGE 223.

	LIGHT FIRING.	HEAVY FIRING.
Coal consumed per day of eleven hours.....	2,449 lbs.	4,435 lbs.
Net combustible consumed per day of eleven hours	2,117 lbs.	3,811 lbs.
Water evaporated per day of eleven hours....	18,800 lbs.	32,696 lbs.
Equivalent evaporation from and at 212° per pound of coal.....	8.97 lbs.	8.60 lbs.
Equivalent evaporation from and at 212° per pound of net combustible.....	10.37 lbs.	10.02 lbs.
Equivalent evaporation from and at 212° per hour, per square foot of heating surface....	3.28 lbs.	5.71 lbs.
Weight of air supplied per pound of coal consumed	14.89 lbs.	14.37 lbs.
Mean temperature of gases entering the chimney.....	425°	563°

The above table shows a good rate of evaporation, but it does not surpass that of a good tubular, which can be furnished for a great deal less money for the boiler itself, and scarcely half as much for the setting in brick work.

This boiler weighed, with its accessories, 31,900 pounds, and cost \$2,141.22 for the boiler, and \$580.80 for the setting, or a total cost of \$2,722.02

Flue boilers—The transition from a cylinder to a flue boiler is an easy and a natural one, and probably suggested itself as a means of utilizing the waste gases passing into the chimney.

Two-flue boilers (figure 55) are in very common use in this country, and range in diameter from thirty-six to forty-

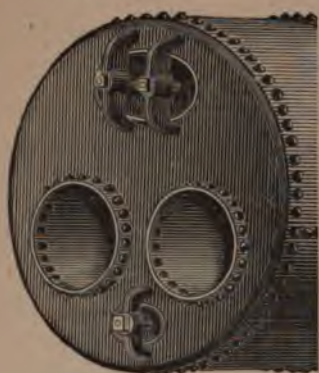


FIGURE 55.

eight inches; perhaps there are more forty-two inches in diameter than any other size. This style of boiler varies in length from five to eight diameters. The diameters of the flues approximate very closely one-third of the diameter of the shell. This boiler has been long tried, and has stood the test well. It affords good facilities for cleaning and inspection; steams well and permits a good circulation of water.

The following table (LXIII) gives the proportions used by the writer, and will be found to accord very closely with the best average practice. The heating surface is two-thirds of the circumference of the shell multiplied into its length, to which is added the whole surface of the flues. The weights given are for one-quarter inch iron, in all cases, for the shells, and for the heads, as follows:

36 and 38 inches diameter.....	$\frac{3}{8}$ inch thick.
40, 42, 44, 46 inches diameter.....	$\frac{7}{16}$ inch thick.
48 inches diameter.....	$\frac{1}{2}$ inch thick

The weights include a 9×15 man hole plate above, and a hand hole, or smaller man hole plate, below the flues; also, the necessary stays and braces for the heads. The weights do not include a dome, or fixtures of any kind.

These tabular weights agree so closely to the average actual weights of the boilers after completion that they will be found sufficiently accurate to use in making contracts.

TABLE LXIII.

SHOWING PROPORTIONS, HEATING SURFACE AND HORSE POWER OF TWO-FLUE BOILERS.

SHELL.		FLUES.		HEATING SURFACE OF SHELL AND WHOLE OF FLUES.	APPROXIMATE WEIGHT OF SHELL.	HORSE POWER AT 12 FEET.
DIAMETER.	LENGTH.	DIAMETER.	THICKNESS.			
INCHES.	FEET.	INCHES.	INCHES.	SQUARE FEET.	POUNDS.	
36	14	12	$\frac{1}{4}$	176	3,238	14.7
	16	12	$\frac{1}{4}$	201	3,619	16.8
	18	12	$\frac{1}{4}$	227	4,000	18.9
	20	12	$\frac{1}{4}$	252	4,381	21.0
38	14	12	$\frac{1}{4}$	181	3,364	15.0
	16	12	$\frac{1}{4}$	206	3,757	17.2
	18	12	$\frac{1}{4}$	233	4,150	19.4
	20	12	$\frac{1}{4}$	259	4,548	21.6
40	16	14	$\frac{1}{4}$	229	4,117	19.1
	18	14	$\frac{1}{4}$	256	4,553	21.3
	20	14	$\frac{1}{4}$	284	4,987	23.7
	22	14	$\frac{1}{4}$	314	5,424	26.2
	24	14	$\frac{1}{4}$	342	5,860	28.5

TABLE LXIII—CONTINUED.

SHELL.		FLUES.		HEATING SURFACE OF $\frac{3}{4}$ SHELL AND WHOLE OF FLUES.	APPROXIMATE WEIGHT OF $\frac{1}{4}$ SHELL.	HORSE POWER AT 12 FEET.
DIAMETER.	LENGTH.	DIAMETER.	THICKNESS.			
INCHES.	FEET.	INCHES.	INCHES.	SQUARE FEET.	POUNDS.	
42	16	14	$\frac{1}{4}$	235	4,243	19.6
	18	14	$\frac{1}{4}$	264	4,700	22.0
	20	14	$\frac{1}{4}$	294	5,157	24.5
	22	14	$\frac{1}{4}$	323	5,614	26.9
	24	14	$\frac{1}{4}$	352	6,071	29.3
44	16	16	$\frac{1}{4}$	257	4,561	21.4
	18	16	$\frac{1}{4}$	288	5,046	24.0
	20	16	$\frac{1}{4}$	322	5,531	26.8
	22	16	$\frac{1}{4}$	353	6,016	29.4
	24	16	$\frac{1}{4}$	386	6,501	32.2
46	16	17	$\frac{1}{4}$	270	4,800	22.5
	18	17	$\frac{1}{4}$	305	5,311	25.4
	20	17	$\frac{1}{4}$	339	5,822	28.3
	22	17	$\frac{1}{4}$	373	6,333	31.1
	24	17	$\frac{1}{4}$	407	6,844	33.9
48	26	17	$\frac{1}{4}$	441	7,355	36.8
	16	18	$\frac{1}{4}$	284	5,031	23.7
	18	18	$\frac{1}{4}$	321	5,566	26.8
	20	18	$\frac{1}{4}$	356	6,101	29.7
	22	18	$\frac{1}{4}$	392	6,636	32.7
	24	18	$\frac{1}{4}$	427	7,171	35.6
	26	18	$\frac{1}{4}$	464	7,706	38.7
	28	18	$\frac{1}{4}$	499	8,241	41.6
	30	18	$\frac{1}{4}$	533	8,766	44.4

The thickness of flues is given in the table as $\frac{1}{4}$ inch in all cases. For diameters greater than 14 inches, $\frac{5}{16}$ iron may be used with advantage. It is not an easy matter to make thick flues of small diameters, and, in consequence, they seldom exceed $\frac{1}{4}$ inch, except for very high pressures. The sheets are usually made for 30 inch lengths. How much a circumferential seam of rivets, together with the double thickness of iron, adds to the strength of the flue to resist collapse, when occurring at every 30 inches of its length, is not known to the writer, and he is not aware that any experiments of that kind on long tubes, for different thickness of metal, have ever been made.

The following table gives the thickness of flues used by the boiler makers at Pittsburg, Pa., and allowed by the Government Inspectors for boilers, although it is known that they are intended for river service, where 150 lbs. to the square inch is not uncommon in emergencies:

DIAMETER OF FLUE.	THICKNESS.
16 inches.....	.31 inch.
15 inches.....	.29 inch.
14 inches.....	.27 inch.
13 inches.....	.25 inch.
12 inches.....	.23 inch.
11 inches.....	.21 inch.
10 inches.....	.19 inch.
9 inches.....	.17 inch.
8 inches.....	.15 inch.
7 inches.....	.13 inch.
6 inches.....	.11 inch.

Five flue boilers—Sometimes the flues are decreased in diameter and increased in number for the same diameter of shell in order to carry a higher pressure than would be allowed in a two flue boiler. It is a common practice, in some sections of the country, to make a boiler with five flues, as shown in figure 56. They are shown in the engraving as being all of the same diameter. The flues are

often made of several diameters for the same boiler, and will not vary much from sizes given below :

DIAMETER OF BOILER.	DIAMETER OF FLUES.
44 inches.....	{ 2 — 10 inches. 3 — 8 inches.
46 inches	{ 1 — 13 inches. 2 — 9 inches. 2 — 8 inches.
48 inches	{ 1 — 12 inches. 2 — 10 inches. 2 — 8 inches.
50 inches.....	{ 1 — 14 inches. 2 — 10 inches. 2 — 8 inches.

The above was intended for lap riveted flues. It is now possible to get lap welded flues, of large diameter; these being free from joints, perfectly cylindrical, and practically uniform in quality, are recommended as being in all respects superior to the ordinary riveted flue, except the strength which the lap riveted joints gives the flues to resist collapse. When these lap welded flues are used, it is, on the whole, preferable to make the diameters the same for all the flues, instead of having two or three sizes, as given above.

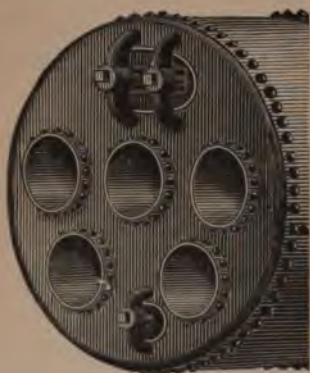


FIGURE 56.

The following table (LXIV) gives the proportions, weight, etc., including all the details mentioned in connection with the two flue boilers. As lap welded flues are not sold by weight, two columns are given in the table, in order to figure the shell by the pound and the tubes by the foot. The total weight is given for shipping or other purposes.

TABLE LXIV.
SHOWING PROPORTIONS, HEATING SURFACE AND HORSE POWER OF
FIVE-FLUE BOILERS.

SHELL.		FLUES. DIAMETER.	HEATING SURFACE, $\frac{3}{4}$ SHELL AND WHOLE OF FLUES.	WEIGHT.			HORSE POWER AT 12 FEET.
DIAMETER.	LENGTH.			SHELL.	FLUES.	TOTAL.	
INCHES.	FEET.	INCHES.	SQ. FEET.	POUNDS.	POUNDS.	POUNDS.	
36	12	7	185	1,933	746	2,679	15.4
	14	7	218	2,161	871	3,032	18.2
	16	7	246	2,388	995	3,383	20.5
38	12	7	190	2,045	746	2,791	15.8
	14	7	223	2,286	871	3,157	18.6
	16	7	251	2,527	995	3,522	20.9
	18	7	284	2,769	1,119	3,888	23.7
40	12	8	208	2,139	907	3,046	17.3
	14	8	242	2,392	1,058	3,450	20.2
	16	8	281	2,645	1,209	3,854	23.4
	18	8	314	2,897	1,360	4,257	26.2
	20	8	348	3,149	1,511	4,660	29.0
42	14	9	268	2,506	1,260	3,766	22.3
	16	9	307	2,771	1,440	4,211	25.6
	18	9	346	3,034	1,620	4,654	28.8
	20	9	385	3,298	1,800	5,098	32.1
	22	9	424	3,562	1,980	5,542	35.3
44	14	10	293	2,617	1,554	4,171	24.4
	16	10	333	2,893	1,775	4,668	27.8
	18	10	373	3,169	1,997	5,166	31.1
	20	10	414	3,445	2,219	5,664	34.5
	22	10	459	3,721	2,441	6,162	38.3
	24	10	499	3,997	2,663	6,660	41.6

TABLE LXIV—CONTINUED.

SHELL.		FLUES. DIAMETER.	HEATING SURFACE, $\frac{3}{4}$ SHELL AND WHOLE OF FLUES.	WEIGHT.			Horse POWER AT 12 FEET.
DIAMETER.	LENGTH.			SHELL.	FLUES.	TOTAL.	
INCHES.	FEET.	INCHES.	SQ. FEET.	POUNDS.	POUNDS.	POUNDS.	
46	16	10	338	3,048	1,775	4,823	28.2
	18	10	380	3,339	1,997	5,336	31.7
	20	10	421	3,630	2,219	5,849	35.1
	22	10	467	3,921	2,441	6,362	38.9
	24	10	508	4,212	2,663	6,875	42.3
48	16	10	344	3,173	1,775	4,948	28.7
	18	10	386	3,476	1,997	5,473	32.2
	20	10	428	3,779	2,219	5,998	35.7
	22	10	474	4,082	2,441	6,523	39.5
	24	10	516	4,385	2,663	7,048	43.0

Six inch flue boiler—Another arrangement of lap welded flues, and one which is already very popular in some sections of the country, is to make a boiler with as many six inch flues as it will contain below the upper limit of tube surface. Figure 57 shows an end elevation of a forty-four inch boiler fitted with nine flues six inches in diameter, riveted at each end to flanged heads. If the heads are made of the best flange iron there is no difficulty in flanging the flue holes within three inches of each other. Owing to the great difficulty in keeping the heads flat machine flanging is recommended. It is also recommended that one head be flanged *in* and the other flanged *out*. The flue holes shown in figure 57 are said to be flanged *out*; that is, they are flanged in the opposite direc-

tion to the flange intended for the shell. To those who have never made such a boiler it would appear impracticable to properly rivet the flues at the rear end, or in the head containing the flue holes flanged *in*. A few special tools for holding the rivets in place are needed, and, perhaps, a few special riveting hammers.

Begin with the bottom flues, insert the rivets from the inside of the boiler, and rivet them on the inside of the flue; this can be done with little difficulty from the outside of the boiler. The rivets should be half an inch in diameter for six inch flues.

This boiler steams well, and is easily kept clean. The following table gives the proportions, as used by the writer, together with the heating surface, etc. The thickness of shell for all boilers up to and including forty-eight inches is one-quarter inch. The fifty-four and sixty inch shells are five-sixteenths inch, with five-eighths inch heads. All shells double riveted. The weights include the necessary stays, but no dome or fixtures of any kind. No lengths are given for boilers more than twenty feet long, for the reason that manufacturers advance the price on the whole length of tubes when they exceed twenty feet. This advance is so out of proportion to the ordinary market value of boilers that it does not "pay" to use them.



FIGURE 57.

TABLE LXV.
SHOWING PROPORTIONS, HEATING SURFACE AND HORSE POWER OF
BOILERS FITTED WITH SIX-INCH LAP WELDED FLUES.

SHELL.		NUMBER OF FLUES.	HEATING SURFACE, ¾ SHELL AND WHOLE OF FLUES.	WEIGHT.			HORSE POWER AT 12 FEET.
DIAMETER.	LENGTH.			SHELL.	FLUES.	TOTAL.	
INCHES.	FEET.		SQ. FEET.	POUNDS.	POUNDS.	POUNDS.	
42	12	6	201	2,242	673	2,915	16.7
	14	6	235	2,506	785	3,291	19.6
	16	6	268	2,770	897	3,667	22.3
	18	6	302	3,034	1,009	4,043	25.2
	20	6	336	3,298	1,122	4,420	28.0
44	12	9	262	2,341	1,009	3,350	21.8
	14	9	306	2,617	1,178	3,795	25.5
	16	9	349	2,893	1,346	4,239	29.1
	18	9	392	3,169	1,514	4,683	32.7
	20	9	437	3,445	1,682	5,127	36.4
46	12	10	285	2,466	1,122	3,588	23.8
	14	10	332	2,757	1,308	4,065	27.7
	16	10	379	3,048	1,495	4,543	31.6
	18	10	428	3,339	1,682	5,021	35.7
	20	10	475	3,630	1,869	5,499	39.6
48	12	12	327	2,568	1,346	3,914	27.3
	14	12	381	2,871	1,570	4,441	31.2
	16	12	436	3,174	1,794	4,968	36.3
	18	12	490	3,477	2,019	5,496	40.8
	20	12	545	3,780	2,243	6,023	45.4

TABLE LXV—CONTINUED.

SHELL.		NUMBER OF FLUES.	HEATING SURFACE, ¾ SHELL AND WHOLE OF FLUES.	WEIGHT.			HORSE POWER AT 12 FEET.
DIAME- TER.	LENGTH.			SHELL.	FLUES.	TOTAL.	
INCHES.	FEET.		SQ. FEET.	POUNDS.	POUNDS.	POUNDS.	
54	14	14	440	4,276	1,832	6,108	36.7
	16	14	503	4,708	2,094	6,802	41.9
	18	14	566	5,141	2,355	7,496	47.2
	20	14	628	5,573	2,617	8,190	52.3
60	14	18	543	5,077	2,355	7,432	45.3
	16	18	620	5,553	2,692	8,245	51.7
	18	18	697	6,029	3,028	9,057	58.1
	20	18	774	6,505	3,365	9,870	64.5

The above examples suffice to show the combinations, proportions, heating surface and weights of flue boilers in general use. It is possible to make so many combinations by using flues of several diameters in the same boiler that it would unnecessarily cumber the book with tables, if they were all to be taken into account. The weights and heating surface for any other style of flue boilers than those given may be easily determined by using the figures already furnished in the tables.

The following test made by Isaac V. Holmes, M E., Cleveland, Ohio, shows results somewhat over the average for flue boilers. There is no doubt that much of this is due to the superior setting of the boilers, the exceptional richness of the coal, and perfect combustion. The furnace will be described in the chapter on boiler settings:

These tests were made at the Soldiers' Home, near Dayton, Ohio, on the twenty-seventh and twenty-eighth of March, 1877.

Each boiler was fifty-four inch diameter of shell, twenty-eight feet long, four six-inch flues, two ten-inch flues, no steam dome; the feed water was delivered through a mud drum attached to the rear.

Each trial was a continuous run of twelve hours, and was conducted as follows:

The boiler was connected at its regular duty, with steam pressure at fifty pounds by gauge attached to shell, and the level of water at standard mark attached to glass water gauge.

At the time noted, all the burning fuel was drawn from the furnace and the ash pit cleaned. Then the furnace was stocked with coal from that weighed for the test, and the trial commenced.

All coal used during the trial was weighed and delivered in one hundred pound lots.

All water delivered was weighed before it was discharged into feed tank, and at commencement of test was on a level with gauge line. The temperature of the same was observed and entered on the log every fifteen minutes.

At the termination of the twelve hours all the burning fuel on the grates was removed and extinguished, and all unburned fuel credited back, while the clinker and ashes were weighed dry, and the water, both in the boiler and feed tank, was left at the standard marks.

Summary of results—Condition of atmosphere the same on both days of trial:

DUTY.	NO. 1 BOILER.	NO. 2 BOILER.
The same on each boiler.....	Heating buildings.	
COAL.		
The same kind for both trials.....	Youghiogheny lump.	

DURATION.	NO. 1 BOILER.	NO. 2 BOILER.
Continuous firing.....	12 hours.	12 hours.
OBSERVATIONS.		
Total amount water weighed to boiler.....	28,521 lbs.	30,423 lbs.
Total amount coal weighed to furnace..	3,433 lbs.	3,700 lbs.
Total amount ashes weighed dry.....	193 lbs.	278 lbs.
Total amount combustible.....	3,240 lbs.	3,421 lbs.
Average temperature feed water in tank.....	106°	118°
Average temperature back connection.	700°	659°
Average temperature uptake.....	446°	476°
Average temperature air in pipe.....	107°	107°
Average temperature air in furnace.....	not taken.	495°
Average pressure steam at boiler.....	48 lbs.	46.5 lbs.
Average pressure steam at main.....	18.5 lbs.	17 lbs.
Average percentage water in steam.....	.126	.053
PERFORMANCE.		
Coal per hour.....	286 lbs.	308.33 lbs.
Combustible per hour.....	270 lbs.	285 lbs.
Water per hour.....	2,380 lbs.	2,535 lbs.
Pounds of water evaporated at 48 lbs. pressure and temperature at 106° per one pound of coal.....	8.31	
Pounds of water evaporated at 46.5 lbs. pressure and temperature of 118° per one pound of coal.....		8.22
Equivalent evaporation from pressure of atmosphere and temperature of 212° per one pound of coal.....	9.43	9.23
Equivalent evaporation from pressure of atmosphere and temperature of 212° per one pound combustible,	9.988	9.983

Conclusions—The evaporation of over nine pounds of water by the combustion of one pound of coal, with a six inch flue boiler, is a strong proof of the economy and efficiency of the Butman furnace, while a close observation of its working showed the combustion was at all times very complete. No smoke evolved by the distillation of the fuel in the furnace, but clear heated gases, which flowed

off underneath and along the sides of the boiler, and from the top of the stack could only be seen the quivering products of combustion floating off into the atmosphere, there being no color or indication of smoke whatever.

Tubular boilers—This type of boiler is so well known as to need little or no description.

Perhaps no other kind of boiler has had such an extensive sale as this; if it is to be used where the feed water is pure and clean, it is then, probably, the "best boiler for the money" in the market, but it is not the boiler to be recommended in all cases. The writer never hesitates to recommend it in cases where the feed water contains no lime or other substances which will form scale; and does not recommend it where the water is bad, unless the means for preventing the scale are known to be efficient. There is quite a diversity of opinion in regard to proportioning tubular boilers. There are those who advocate length rather than diameter; others, advocating the reverse. No doubt much of the confusion on this point arises from a lack of exact knowledge as to the relative values of shell and tube heating surface. It is just here that the error in reckoning horse power by *extent* of heating surface, rather than by *efficiency*, becomes fully apparent. There is a prevailing notion that the power of a tubular boiler may be indefinitely extended, by simply increasing the number of tubes in the shell. This is a mistake. Too many tubes, especially if of small diameters, may so prevent the circulation of the water in the boiler as to dimin-



FIGURE 58.

ish, instead of increase the evaporation. It thus has the effect to induce priming, and may lead to the overheating of the plates immediately over the grates.

The ratio of tube area to grate surface has something to do with the fixing of the maximum number of tubes for any given boiler. The grate area being known, then, one-seventh of this area suffices for the tube area, as the largest admissible under the severest firing in stationary boilers with chimney draft, and for forced draft, if the coal burned per square foot of grate does not exceed twenty pounds per hour. This rate of combustion is in excess of ordinary practice, the common rate being not far from fifteen pounds per hour for each square foot of grate. For this, one-twelfth of the grate area will suffice for the maximum tube area.

The length of tubes is practically limited to twenty feet, as manufacturers do not carry them in stock and charge an additional price per foot for the whole tube when made to order of a greater length. Tubular boilers are seldom made longer than sixteen feet if the tubes are less than four inches in diameter. When five to six inches in diameter they may then be made twenty feet long. Casual observations made on the steaming capacity and temperature of escaping gases show that in tubular boilers having lengths of twelve, fourteen and sixteen feet, and with ordinary slow firing, that the two former are to be preferred to the latter length for tubes three inches in diameter. If a forced draft is employed, then three inch tubes, sixteen feet long, may be used with advantage if a damper is placed in the chimney so as to slightly increase the pressure of the gases flowing through the tubes.

The following table (LXVI) gives the greatest number of tubes which may be inserted in boiler heads for the diameters given, the tubes to be arranged in vertical rows as shown in figure 59, and have a clear space between each

row of one-third the diameter of the tube. The top of the upper row of tubes is approximately three-fifths of the diameter of the boiler. In some cases, however, the tubes are carried a little higher, in order to prevent the end tubes in some of the lower rows from crossing within the line drawn for the minimum water space. In no case does this change equal the half diameter of the tube. By arranging the end tubes in the bottom rows a little differently, the exceptions noted above may be remedied, but no particular objection exists to their remaining where they are.

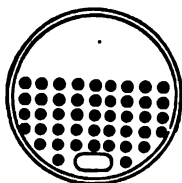


FIGURE 59.

TABLE LXVI.

SHOWING THE GREATEST NUMBER OF TUBES WHICH MAY BE PUT IN A GIVEN HEAD (SUBJECT TO THE CONDITIONS STATED ABOVE)

DIAM- ETER OF BOILER.	DIAMETER OF TUBES.							HAND OR MAN HOLE.
	3	3 $\frac{1}{4}$	3 $\frac{1}{2}$	3 $\frac{3}{4}$	4	4 $\frac{1}{2}$	5	
36	26	23	19	20	16	12	10	6x8
38	32	23	21	20	18	12	14	6x8
40	34	34	25	23	20	14	14	6x8
42	45	38	32	26	25	20	18	6x8
44	48	36	32	30	25	20	16	6x8
46	42	38	34	28	23	21	16	8x12
48	50	38	36	30	26	21	18	8x12
50	55	42	38	34	30	23	20	8x12
52	57	50	48	38	32	26	21	8x12
54	66	55	48	38	36	28	21	8x12
56	72	57	55	48	41	32	23	8x12
58	74	66	55	48	45	32	28	8x12
60	80	68	62	55	46	36	30	8x12

Provision is made in this table for lower hand and man hole plates in all the boilers. The size for 36 to 44 inch boilers, inclusive, is 6×8 inches, and from 46 to 60 inches, 8×12 inches. No tube is located nearer than 2 inches to the shell for diameter 36 to 44 inches, and none nearer than $2\frac{1}{2}$ inches from 46 to 52 inches, and none nearer than 3 inches from 54 to 60 inches diameter of boiler. The diameter of the boiler is that of the inside in all cases.

This table does not allow for a middle space up through the center of the boiler, as shown in figure 60. If the tubes are not placed nearer together than $\frac{1}{2}$ their diameter, and the clear space between the tube and the shell of the boiler is not less than that given on page 240, and the water does not contain impurities which will form scale, it is altogether probable that the circulation will be ample to furnish dry steam, with the number and arrangement of tubes which the table calls for.



FIGURE 60.

If the water is hard and will form scale, then the space shown in figure 60 should be allowed, because incrustation will gradually close the distance between the tubes and prevent proper circulation. This will lessen the number of tubes three to six. In some of the boilers, a row of tubes comes in the center; and in others, a space, so that it will be necessary to re-arrange the tubes. The distance apart from tube to tube, in the central space in the boiler, may properly be fixed by the diameter of the shell.

The following distances may be varied to suit circumstances, but will be found to be ample, in any ordinary case, for tubes less than four inches diameter :

DIAMETER OF BOILER.	DISTANCE APART.
30 inches.....	2 inches.
38 inches.....	2 $\frac{1}{4}$ inches.
40 inches.....	2 $\frac{3}{4}$ inches.
42 inches.....	3 inches.
44 inches.....	3 $\frac{1}{4}$ inches.
46 inches.....	3 $\frac{3}{4}$ inches.
48 inches.....	4 inches.
50 inches.....	4 $\frac{1}{4}$ inches.
52 inches.....	4 $\frac{3}{4}$ inches.
54 inches.....	5 inches.
56 inches.....	5 $\frac{1}{4}$ inches.
58 inches.....	5 $\frac{3}{4}$ inches.
60 inches.....	6 inches.

Tubes four inches in diameter and over, when simply expanded in the heads, are not generally put in shells less than forty-eight inches in diameter. If the space, as given above, does not interfere with the locating of the desired number of tubes, it may be retained. In case it should, the distance may be shortened a little, on account of the greater distance apart of the tubes themselves over those of smaller diameter.

The next table (LXVII) shows the proportions, heating surface, weight and horse power of three-inch tubular boilers. Boilers, thirty-six to forty-four inches inclusive, have a 6×8 hand hole below the tubes; from forty-six to sixty inches, an 8×12 man head similarly fitted. All the boilers have a 9×15 man head above the tubes. The weights do not include a dome or fixtures of any kind, but do include all necessary stays and bracing.

The thickness of shell is one-quarter inch, from thirty-six to forty-eight inches inclusive, and five-sixteenths inch from fifty to sixty inches. The thickness of heads for

36 and 38 inches diameter is.....	$\frac{1}{4}$ inch.
40 to 46 inches diameter is.....	$\frac{7}{16}$ inch.
48 to 52 inches diameter is.....	$\frac{1}{2}$ inch.
54 to 56 inches diameter is.....	$\frac{5}{8}$ inch.
58 to 60 inches diameter is.....	$\frac{3}{4}$ inch.

If the fifty-eight and sixty-inch boilers are to carry more than one hundred and twenty-five pounds of steam, they should be made of steel, rather than increase the thickness of the shell. Longitudinal seams to be double riveted in all cases.

TABLE LXVII.

SHOWING PROPORTIONS, HEATING SURFACE, WEIGHT AND HORSE POWER OF TUBULAR BOILERS FITTED WITH THREE-INCH TUBES.

SHELL.		NUMBER OF TUBES.	HEATING SURFACE, $\frac{3}{4}$ SHELL AND WHOLE OF TUBES.	WEIGHT.			HORSE POWER AT 15 FEET.
DIAMETER.	LENGTH.			SHELL.	TUBES.	TOTAL.	
INCHES	FEET.		SQ. FEET.	POUNDS.	POUNDS.	POUNDS.	
36	8	26	213	1,478	693	2,171	14.2
	10	26	267	1,705	867	2,572	17.8
	12	26	320	1,933	1,040	2,973	21.3
	14	26	374	2,161	1,213	3,374	24.9
	16	26	428	2,389	1,387	3,776	28.5
38	8	32	254	1,563	853	2,416	16.9
	10	32	317	1,804	1,067	2,871	21.1
	12	32	380	2,045	1,280	3,325	25.3
	14	32	443	2,286	1,493	3,779	29.5
	16	32	506	2,527	17,07	4,234	33.7
40	8	34	269	1,632	907	2,539	17.9
	10	34	336	1,885	1,133	3,018	22.4
	12	34	403	2,138	1,360	3,498	26.9
	14	34	470	2,391	1,587	3,978	31.3
	16	34	537	2,644	1,813	4,457	35.8
42	10	45	426	1,978	1,500	3,478	28.4
	12	45	512	2,242	1,800	4,042	34.1
	14	45	598	2,506	2,100	4,606	39.9
	16	45	684	2,770	2,400	5,170	45.6

TABLE LXVII—CONTINUED.

SHELL.		NUMBER OF TUBES.	HEATING SURFACE, $\frac{3}{4}$ SHELL AND WHOLE OF TUBES.	WEIGHT.			Horse POWER AT 15 FEET.
DIAMETER.	LENGTH.			SHELL.	TUBES.	TOTAL.	
INCHES	FEET.		SQ. FEET.	POUNDS.	POUNDS.	POUNDS.	
44	10	48	454	2,065	1,600	3,665	30.3
	12	48	544	2,341	1,920	4,261	36.3
	14	48	634	2,617	2,240	4,857	42.3
	16	48	725	2,893	2,560	5,453	48.3
	18	48	816	3,169	2,880	6,049	54.4
46	10	42	410	2,174	1,400	3,574	27.3
	12	42	492	2,465	1,680	4,145	32.8
	14	42	575	2,756	1,960	4,716	38.3
	16	42	657	3,047	2,240	5,287	43.8
	18	42	739	3,338	2,520	5,858	49.3
48	10	50	477	2,267	1,667	3,934	31.8
	12	50	572	2,569	2,000	4,569	38.1
	14	50	667	2,871	2,333	5,204	44.5
	16	50	763	3,173	2,667	5,840	50.9
	18	50	859	3,476	3,000	6,476	57.3
50	20	50	954	3,778	3,333	7,111	63.6
	10	55	519	3,009	1,833	4,842	34.6
	12	55	623	3,410	2,200	5,610	41.5
	14	55	727	3,811	2,567	6,378	48.5
	16	55	831	4,212	2,933	7,145	55.4
52	18	55	934	4,613	3,280	7,893	62.3
	20	55	1,038	5,014	3,666	8,680	69.2
	12	57	646	3,572	2,280	5,852	43.1
	14	57	754	3,988	2,660	6,648	50.3
	16	57	862	4,404	3,040	7,444	57.5
52	18	57	969	4,820	3,420	8,240	64.6
	20	57	1,077	5,236	3,800	9,036	71.8

TABLE LXVII—CONTINUED.

SHELL.		NUMBER OF TUBES.	HEATING SURFACE, $\frac{2}{3}$ SHELL AND WHOLE OF TUBES.	WEIGHT.			HORSE POWER AT 15 FEET.
DIAME- TER.	LENGTH.			SHELL	TUBES.	TOTAL.	
INCHES	FEET.		SQ. FEET.	POUNDS.	POUNDS.	POUNDS.	
54	12	66	735	3,844	2,640	6,484	49.0
	14	66	858	4,276	3,080	7,356	57.2
	16	66	980	4,708	3,520	8,228	65.3
	18	66	1,102	5,140	3,960	9,100	73.5
	20	66	1,224	5,573	4,400	9,973	81.6
56	12	72	796	4,017	2,880	6,897	53.1
	14	72	929	4,464	3,360	7,824	61.9
	16	72	1,062	4,911	3,840	8,751	70.8
	18	72	1,194	5,358	4,320	9,678	79.6
	20	72	1,326	5,805	4,800	10,605	88.4
58	12	74	818	4,300	2,960	7,260	54.5
	14	74	955	4,762	3,453	8,215	63.7
	16	74	1,091	5,224	3,947	9,171	72.7
	18	74	1,227	5,686	4,440	10,126	81.8
	20	74	1,364	6,148	4,933	11,081	90.9
60	12	80	880	4,601	3,200	7,801	58.7
	14	80	1,027	5,077	3,733	8,810	68.5
	16	80	1,174	5,553	4,267	9,820	78.3
	18	80	1,320	6,029	4,800	10,829	88.0
	20	80	1,467	6,505	5,333	11,838	97.8

In some of the larger boilers in the above table the lengths are carried out to twenty feet. The writer never made a three-inch tubular boiler of that length, neither does he know of any in use, and would not, from data he has, recommend twenty

feet, except in cases where a force blast is used and the combustion complete. It would require a careful adjustment of tube to grate area, and there must be coal enough burned on the grate to insure the tubes being completely filled with gases at all times. Ordinarily, it is better to keep the length at sixteen feet than to go beyond it.

TABLE LXVIII.

SHOWING THE WIDTH AND LENGTH OF GRATES, AND THE AREA IN SQUARE FEET, AS USUALLY SUPPLIED TUBULAR AND FLUE BOILERS. ALSO, THE AMOUNT OF COAL REQUIRED PER HOUR WHEN BURNED AT THE RATE OF 12, 14, 16, 18, 20 POUNDS PER SQUARE FOOT OF GRATE PER HOUR.

DIAMETER OF BOILER.	GRATE.			COAL REQUIRED PER HOUR.				
	WIDTH.	LENGTH	AREA.	12 LBS.	14 LBS.	16 LBS.	18 LBS.	20 LBS.
INCHES.	INCHES.	INCHES.	SQ. FEET.	POUNDS.	POUNDS.	POUNDS.	POUNDS.	POUNDS.
36	45	48	15.0	180	210	240	270	300
38	47	48	15.7	188	220	251	283	314
40	49	48	16.3	196	228	261	293	326
42	51	52	18.4	221	258	294	331	368
44	53	52	19.1	229	267	306	344	382
46	55	52	19.9	239	279	318	358	398
48	57	52	20.6	247	288	329	371	412
50	59	60	24.6	295	344	394	443	492
52	61	60	25.4	305	356	406	457	508
54	63	60	26.3	316	368	421	473	526
56	65	72	32.5	390	455	520	585	650
58	67	72	33.5	402	469	536	603	670
60	69	72	34.5	414	483	552	621	690

The above table gives the sizes of grates usually supplied with tubular boilers, by the writer, when no special orders are given to the contrary. In connection with it is also given the pounds of coal required per hour

for the different rates of combustion given. The sizes of grates as given in the table may, in general, be reduced without loss of efficiency. See page 203.

The ordinary rate of combustion for bituminous coal will vary from twelve to sixteen pounds per hour, per square foot of grate surface. The two last columns in the table should not be used in advance of construction, unless the chimney draft is known to be sufficient to burn that quantity, or unless a force draft is to be employed.

In order to facilitate any needed calculations, in which it would be necessary to know the relation of tube to grate area, the following table (LXIX) is supplied, in which the area is given in square feet. Tubes are always sold by outside diameter. The internal areas corresponding to these diameters are as follows:

TABLE LXIX.
INTERNAL AREAS OF LAP WELDED TUBES.

DIAM- ETER.	THICKNESS.	INTERNAL AREA.	DIAM- ETER.	THICKNESS.	INTERNAL AREA.
INCHES.	INCHES.	SQ. INCHES.	INCHES.	INCHES.	SQUARE INCHES.
2	0.109	6.083	4	0.130	10.992
3 $\frac{1}{4}$	0.119	7.125	4 $\frac{1}{2}$	0.130	14.126
3 $\frac{1}{2}$	0.119	8.357	5	0.140	17.497
3 $\frac{3}{4}$	0.119	9.687			

It will be understood that this table is to be used in connection with and is to be regarded as supplementary to table LXVI. This will be found quite useful in the re-arranging of grate surface.

TABLE LXX.

SHOWING THE INTERNAL AREAS OF TUBES FOR THE DIAMETERS AS GIVEN BELOW, AND FOR THE NUMBER OF TUBES GIVEN IN TABLE LXVI, ON PAGE 240. THE AREAS ARE GIVEN IN SQUARE FEET.

DIAMETER OF BOILER	DIAMETERS OF TUBES.						
	3	3½	3½	3¾	4	4½	5
36	1.10	1.14	1.10	1.35	1.22	1.18	1.22
38	1.35	1.14	1.22	1.35	1.37	1.18	1.70
40	1.44	1.68	1.45	1.55	1.53	1.37	1.70
42	1.90	1.88	1.86	1.75	1.91	1.96	2.19
44	2.03	1.78	1.86	2.02	1.91	1.96	1.94
46	1.77	1.88	1.97	1.88	1.76	2.06	1.94
48	2.11	1.88	2.09	2.02	1.98	2.06	2.19
50	2.32	2.08	2.21	2.29	2.29	2.26	2.43
52	2.41	2.47	2.79	2.56	2.44	2.55	2.55
54	2.79	2.72	2.79	2.56	2.75	2.75	2.55
56	3.04	2.82	3.19	3.23	3.13	3.14	2.79
58	3.13	3.27	3.19	3.23	3.44	3.14	3.40
60	3.38	3.36	3.60	3.70	3.51	3.53	3.65

Should it be found necessary to re-arrange the grate surface from that given in the preceding tables, it is recommended that the lengths of grates be kept the same and diminished in width, rather than shortened. The next table shows the relation of tube to grate area. The increase shown in the line opposite forty-six inches diameter of boiler is due to the less number of tubes in the boilers, brought about by the insertion of an 8×12 man hole instead of a 6×8 hand hole, which was used in the smaller boilers. This table is to be regarded as supplementary to tables LXVIII and LXX.

TABLE LXXI.

SHOWING THE RELATION OF GRATE AREA, AS GIVEN IN TABLE LXVIII, TO THE TUBE AREA AS GIVEN IN TABLE LXX. THIS TABLE EXPRESSES THE RATIO IN FRACTIONS OF THE GRATE SURFACE. THE VALUES WERE OBTAINED BY DIVIDING THE GRATE BY THE TUBE AREA.

DIAMETER OF BOILER	DIAMETER OF TUBES.						
	3	3½	3½	3¾	4	4½	5
36	13.6	13.2	13.6	11.1	12.3	12.7	12.3
38	11.6	13.8	12.8	11.5	11.5	13.3	9.2
40	11.3	9.7	11.2	10.5	10.7	11.9	9.6
42	9.7	9.8	9.9	10.5	9.6	9.4	8.4
44	9.4	10.7	10.3	9.5	10.0	9.7	9.8
46	18.6	10.6	10.1	10.6	11.3	9.7	10.3
48	9.8	11.0	9.9	10.2	10.4	10.0	9.4
50	10.6	11.8	11.1	10.7	10.7	10.9	10.1
52	10.5	10.3	9.1	9.9	10.4	10.0	10.0
54	9.4	9.7	9.4	10.3	9.6	9.6	10.3
56	10.7	11.5	10.2	10.1	10.4	10.4	11.6
58	10.7	10.2	10.5	10.4	9.7	10.7	9.9
60	10.2	10.3	9.6	9.3	9.8	9.8	9.5

There are more tubular boilers fitted with three-inch tubes than perhaps any other size, but in some sections of the country three and a half and four-inch tubes are more common. The next two tables give the same particulars as those given in the three-inch tables. The shells, heads, man holes, etc., are in no respect different from those contained in table LXVII. Boilers having diameters from thirty-six to forty inches inclusive are not given, as three and a half inch tubes are not often put in boilers of such small sizes.

TABLE LXXII.

SHOWING PROPORTIONS, HEATING SURFACE, WEIGHT AND HORSE POWER OF TUBULAR BOILERS FITTED WITH $3\frac{1}{2}$ INCH TUBES.

SHELL.		NUMBER OF TUBES.	HEATING SURFACE, $\frac{2}{3}$ SHELL AND WHOLE OF TUBES.	WEIGHT.			HORSE POWER AT 15 FEET.
DIAMETER.	LENGTH.			SHELL.	TUBES.	TOTAL.	
INCHES	FEET.		SQ. FEET.	POUNDS.	POUNDS.	POUNDS.	
42	12	32	440	2,242	1,640	3,882	29.3
	14	32	514	2,506	1,914	4,420	34.3
	16	32	586	2,770	2,187	4,957	39.1
	18	32	660	3,034	2,460	5,494	44.0
	20	32	733	3,298	2,734	6,032	48.9
44	12	32	444	2,341	1,640	3,981	29.6
	14	32	519	2,617	1,914	4,531	34.6
	16	32	592	2,893	2,187	5,080	39.5
	18	32	666	3,169	2,460	5,629	44.4
	20	32	740	3,445	2,734	6,179	49.3
46	12	34	470	2,465	1,743	4,208	31.3
	14	34	548	2,756	2,034	4,790	37.2
	16	34	626	3,047	2,324	5,371	41.7
	18	34	706	3,338	2,615	5,953	47.1
	20	34	784	3,629	2,905	6,534	52.3
48	12	36	497	2,569	1,846	4,415	33.1
	14	36	579	2,871	2,153	5,024	38.6
	16	36	662	3,173	2,461	5,634	44.1
	18	36	745	3,476	2,768	6,244	49.7
	20	36	828	3,778	3,076	6,854	55.2
50	12	38	523	3,410	1,948	5,358	34.9
	14	38	609	3,811	2,273	6,084	40.6
	16	38	697	4,212	2,597	6,809	46.5
	18	38	784	4,613	2,922	7,535	52.3
	20	36	871	5,014	3,247	8,261	

TABLE LXXII—CONTINUED.

ELL. LENGTH.	NUMBER OF TUBES.	HEATING SURFACE, $\frac{3}{4}$ SHELL AND WHOLE OF TUBES.	WEIGHT.			HORSE POWER AT 15 FEET.
			SHELL.	TUBES.	TOTAL.	
FEET.		SQ. FEET.	POUNDS.	POUNDS.	POUNDS.	
12	48	637	3,752	2,461	6,213	42.5
14	48	743	3,988	2,871	6,859	49.5
16	48	849	4,404	3,281	7,685	56.6
18	48	955	4,820	3,691	8,511	63.7
20	48	1,062	5,236	4,101	9,337	70.8
12	48	640	3,844	2,461	6,305	42.7
14	48	747	4,276	2,871	7,147	49.8
16	48	855	4,708	3,281	7,989	57.0
18	48	962	5,140	3,691	8,831	64.1
20	48	1,068	5,573	4,101	9,674	71.2
12	55	722	4,017	2,820	6,837	48.1
14	55	843	4,464	3,289	7,753	56.2
16	55	962	4,911	3,759	8,670	64.1
18	55	1,083	5,358	4,229	9,587	72.2
20	55	1,203	5,805	4,699	10,504	80.2
12	55	726	4,300	2,820	7,120	48.4
14	55	848	4,762	3,289	8,051	56.5
16	55	968	5,224	3,759	9,183	64.5
18	55	1,089	5,686	4,229	9,915	72.6
20	55	1,210	6,148	4,699	10,847	80.7
12	62	786	4,601	3,178	7,779	52.4
14	62	917	5,077	3,708	8,785	61.1
16	62	1,048	5,553	4,238	9,791	69.9
18	62	1,178	6,029	4,768	10,797	78.5
20	62	1,309	6,505	5,297	11,802	87.3

It is not a common thing to see tubular boilers fitted with four-inch tubes. There are some sections of the country, however, where they are much in favor. Most of them are made of large diameters—that is, in the neighborhood of five feet. Those who have used them speak of them in the highest terms. No doubt much of their popularity is due to the very efficient circulation of water in the boiler, thereby preventing priming, and all the annoyance and trouble incident to it.

TABLE LXXIII.

SHOWING PROPORTIONS, HEATING SURFACE, WEIGHT AND HORSE POWER OF TUBULAR BOILERS FITTED WITH FOUR-INCH TUBES.

SHELL.		NUMBER OF TUBES.	HEATING SURFACE, $\frac{3}{4}$ SHELL AND WHOLE OF TUBES.	WEIGHT.			HORSE POWER AT 15 FEET.
DIAME- TER.	LENGTH.			SHELL.	TUBES.	TOTAL.	
INCHES	FEET.		SQ. FEET.	POUNDS.	POUNDS.	POUNDS.	
48	12	26	428	2,569	1,660	4,229	28.5
	14	26	498	2,871	1,937	4,808	33.2
	16	26	570	3,173	2,213	5,386	38.0
	18	26	641	3,476	2,490	5,966	42.7
	20	26	713	3,778	2,766	6,544	47.5
50	12	30	482	3,410	1,915	5,325	32.1
	14	30	562	3,811	2,234	6,045	37.5
	16	30	643	4,212	2,553	6,765	42.9
	18	30	722	4,613	2,873	7,486	48.1
	20	30	803	5,014	3,192	8,206	53.5
52	12	32	511	3,752	2,043	5,795	34.1
	14	32	596	3,988	2,383	6,371	39.7
	16	32	681	4,404	2,734	7,138	45.4
	18	32	766	4,820	3,064	7,884	51.1
	20	32	852	5,236	3,405	8,641	56.8

TABLE LXXIII—CONTINUED.

NAME- ER.	SHELL.		NUMBER OF TUBES.	HEATING SURFACE, $\frac{3}{4}$ SHELL AND WHOLE OF TUBES.	WEIGHT.			HORSE POWER AT 15 FEET.
	LENGTH.				SHELL.	TUBES.	TOTAL.	
INCHES	FEET.		SQ. FEET.	POUNDS.	POUNDS.	POUNDS.		
54	12	36	565	3,844	2,298	6,142	37.7	
	14	36	660	4,276	2,681	6,957	44.0	
	16	36	754	4,708	3,064	7,772	50.3	
	18	36	849	5,140	3,447	8,587	56.6	
	20	36	942	5,573	3,830	9,403	62.8	
56	12	41	632	4,017	2,617	6,634	42.1	
	14	41	738	4,464	3,054	7,518	49.2	
	16	41	843	4,911	3,490	8,401	56.2	
	18	41	949	5,358	3,926	9,284	63.3	
	20	41	1,054	5,805	4,362	10,167	70.3	
58	12	45	686	4,300	2,873	7,173	45.7	
	14	45	802	4,762	3,352	8,114	53.5	
	16	45	916	5,224	3,830	9,054	61.1	
	18	45	1,030	5,686	4,309	9,995	68.7	
	20	45	1,144	6,148	4,788	10,936	76.3	
60	12	46	704	4,601	2,936	7,537	46.9	
	14	46	821	5,077	3,426	8,503	54.7	
	16	46	939	5,553	3,916	9,469	62.6	
	18	46	1,055	6,029	4,405	10,434	70.3	
	20	46	1,172	6,505	4,894	11,399	78.1	

The following evaporative test of a tubular boiler, in a
 pouring mill at Bellevue, Ohio, is by Mr. Holmes. The
 dimensions of the boiler are as follows:

Diameter of boiler.....60 inches.
 Length of boiler.....15 feet.
 Number of four-inch tubes.....51
 Grate surface.....26 square feet.

The coal used is an Ohio variety, known as Massillon lump. The duration of trial was ten hours.

OBSERVATIONS.

Total amount water weighed to boiler.....	23,790 lbs.
Total amount coal weighed to furnace.....	4,050 lbs.
Total amount ash and clinker weighed dry.....	220 lbs.
Total amount combustible.....	3,830 lbs.
Average temperature feed water in tank.....	99°
Average temperature gases in uptake.....	479°
Average temperature air in fire room.....	93°
Average pressure steam in boiler.....	72 lbs.
Average percentage water in steam.....	None.

PERFORMANCE.

Coal per hour.....	405 lbs.
Combustible per hour.....	383 lbs.
Water per hour.....	2,870 lbs.

RESULTS.

Pounds of water evaporated at 72 lbs. pressure and temperature of 99° per pound of coal.....	7.08 lbs.
Equivalent evaporation from pressure of atmosphere and temperature of 212° per pound of coal.....	8.15 lbs.
Equivalent evaporation from pressure of atmosphere and temperature of 212° per pound of combustible.....	8.61 lbs.

This boiler was afterwards reset, and an equivalent evaporation at atmospheric pressure from and at 212° was obtained of 11.7 pounds of water, per pound of net combustible, or a gain of over 36 per cent.

A compound tubular steam boiler, built by Mr. E. H. Ashcroft, Boston, Mass., is shown in figure —. The engraving was made from a photograph of a boiler having the following dimensions :



FIGURE 61.

Length of boiler.....	12 feet.
Diameter.....	54 inches.
118 tubes, each 3 inches diameter.....	12 feet long.
Diameter of steam dome.....	32 inches.
Length of steam dome.....	12 feet.
Heating surface.....	1,281 square feet.
Horse power.....	85

This boiler is being well received, and results show it to be economical in fuel. Tests show an equivalent evaporation from and at 212° of over ten pounds of water per pound of coal. The writer expected to be able to give a detailed account of the tests made to determine the capacity and economy of this boiler, but they were not received at the time of making up this form for the press.

CHAPTER XI.

INTERNALLY FIRED BOILERS.

The Cornish Boiler—The Lancashire Boiler—The Fairbairn Boiler—The Galloway Boiler—Vertical Flue Boilers—The Shapley Boiler—The Baxter Boiler—Vertical Tubular Boilers—Snyder's Vertical Boiler—Flynn's Vertical Boiler—Sulter's Boiler—Portable Boilers—Semi-Portable Boilers—Locomotive Boilers.

The internally fired boilers, in common use in this country, are either vertical flue or tubular boilers, or of the locomotive type. In Europe, horizontal boilers, fitted with internal flues, are very common and of a type rarely seen in this country. In England, the internally fired boilers are usually of the Cornish or the Lancashire varieties; there has been a growing dislike to externally fired boilers in that country for many years, during which time the above named boilers have been growing in favor, and are now so thoroughly intrenched behind public opinion, that it would require a remarkably good showing in economy and durability in a rival to gain similar popularity.

The Cornish boiler owes its name to the circumstance of its having been first introduced in Cornwall, England. The original inhabitants of Cornwall were Celts, speaking the Cornish language, which, though now extinct, or no longer spoken by the people, the name of Cornish still lives, and is applied to many technical names—for example, Cornish mining, Cornish agriculture, etc.; hence, Cornish boilers, meaning thereby a particular kind of boiler originally in or peculiar to Cornwall.

This boiler was introduced early in the present century, by Richard Trevithick, an English engineer, born in Cornwall, and one whose name is inseparably connected with the modern steam engine.

This boiler consists of a horizontal cylindric shell, with flat ends and fitted with one large flue passing through from front to back of the boiler and securely fastened to the two ends by riveted joints. This large flue contains the grate on which the fuel is burned, the products of combustion passing through the flue to the back end of the boiler, returning, by a suitable arrangement of the brick work along the sides of the boiler to near the front end, thence downward and along the bottom of the boiler to the rear end, and from thence to the chimney. This arrangement of exterior flues is shown in figure 62.

A Cornish boiler is to be distinguished from a single flue boiler in its having the furnace arranged *in the flue*, and thus being an internally fired boiler.

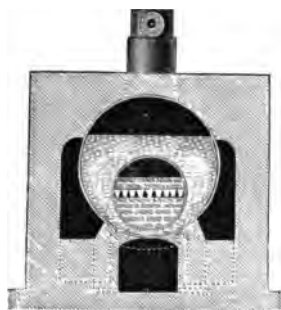


FIGURE 62.

The usual course of heated gases in any arrangement of boiler and furnace is from below upwards. It was first shown by Peclet and is now generally recognized, that a great advantage in point of thorough convection of heat and consequently in economy of fuel, is gained by causing the course of the hot gas to be on the whole from *above downwards*; because then, the hottest strata of the furnace gas, being uppermost, spread themselves out above the denser and colder strata which are below, and so diffuse themselves more uniformly throughout all the passages than they do when made to ascend from below.*

* Rankine.

It would naturally be inferred from an inspection of the engraving that the heating surface is of the best possible arrangement to insure economy of fuel. The feed water enters the boiler near the bottom, where the water is coolest; as it rises becomes more highly heated until the surface is reached, where the steam is given off. There is ample facility for circulation, and the conditions are favorable to rapid evaporation. The large water surface lessens the tendency to priming and thus practically insures dry steam.

Under the most favorable conditions, as regards construction, fuel used and rate of combustion, about eight pounds of water may be evaporated per pound of coal. In this respect the Cornish boiler is about on an equality with our ordinary cylinder boiler. The rate of combustion in Cornish boilers is not far from ten pounds of coal per square foot of grate, in good ordinary firing, and from this down to five or six pounds in slow firing.

These boilers must, of necessity, be of large diameter when required to be of any considerable power. This also necessitates a large flue, in order to afford the necessary grate area and heating surface. Increasing the diameter of the flue decreases its power to resist collapse, which may occur either by overpressure or overheating. These flues are often strengthened by means of heavy wrought iron rings, which are secured to the ends where the sections are to be joined to form a continuous flue. Figure 63 represents such a joint. This ring of angle iron gives the flue great stiffness, and increases its power to resist collapse by shortening the length of the span between supports. A much better device is that of Mr. Adamson, shown in figure 64. The flue is made in sections, with welded seams and flanged ends, which are



FIGURE 63.



FIGURE 64.

secured end to end by riveted joints, as shown, rendering collapse almost impossible; it is, also, a very superior expansion joint, thus preventing the shell being strained, as is often the case with plain flues, and presents a further advantage in that both the rivets and edges of the plates are kept entirely free from the action of the fire.

When a fire is started in any internally fired boiler, having a large flue, such as the Cornish or Lancashire, the flue will be heated first, and will expand in length a considerable distance before the external plates, or the shell of the boiler, has received any considerable degree of heat. Unless some provision is made for this unequal expansion, it is likely to lead to a great deal of annoyance by leaky joints, if not to something more serious in the way of rupture.

The following table gives the principal dimensions of Cornish boilers, as taken from the catalogue of Abbott & Co., Newark-upon-Trent, England:

The Lancashire boiler is an internally fired boiler, and differs from the Cornish in having two flues and furnaces instead of one. It was introduced, in 1844, by Fairbairn and Hetherington in Manchester, and is, therefore, called a Lancashire boiler. The insertion of two smaller flues in the shell of a boiler, instead of one large one, was to strengthen the boiler against collapse. This is, perhaps, the most popular for large boilers of any in England to-day. Figure 65 represents a longitudinal section, and figure 66 a cross section, of a Lancashire boiler.

TABLE LXXIV.

SHOWING THE PRINCIPAL DIMENSIONS OF "NEWARK" STANDARD SIZE CORNISH BOILERS.

HORSE POWER.	SHELL.		DIAMETER OF FLUE. ^o	DOME.		THICKNESS AND QUALITY OF PLATES.				APPROX- IMATE WEIGHT.
	DIAMETER.	LENGTH		DIAMETER.	HEIGHT	SHELL	ENDS.	FLUE.	DOME.	
	FT. IN.	FT. IN.	FT. IN.	FT. IN.	FT. IN.	INCH.	INCH.	INCH.	INCH.	POUNDS.
2	2 9	6 0	1 3	1 0	1 0	$\frac{5}{16}$ B	$\frac{3}{8}$ BB	$\frac{3}{8}$ B	$\frac{5}{16}$ BB	1,900
4	3 9	7 6	2 0	1 3	1 6	$\frac{3}{8}$ B	$\frac{1}{2}$ BB	$\frac{3}{8}$ B	$\frac{3}{8}$ BB	3,248
6	4 3	10 0	2 2	1 6	1 9	$\frac{3}{8}$ B	$\frac{1}{2}$ BB	$\frac{3}{8}$ B	$\frac{3}{8}$ BB	4,480
8	4 4	13 0	2 2	1 6	1 9	$\frac{3}{8}$ B	$\frac{1}{2}$ BB	$\frac{3}{8}$ B	$\frac{3}{8}$ BB	5,824
10	4 6	14 0	2 2	1 9	2 0	$\frac{3}{8}$ B	$\frac{1}{2}$ BB	$\frac{3}{8}$ B	$\frac{3}{8}$ BB	6,720
12	4 8	15 0	2 4	1 9	2 0	$\frac{3}{8}$ B	$\frac{1}{2}$ BB	$\frac{3}{8}$ B	$\frac{3}{8}$ BB	7,280
14	4 9	16 0	2 4	1 9	2 0	$\frac{3}{8}$ B	$\frac{1}{2}$ BB	$\frac{3}{8}$ B	$\frac{3}{8}$ BB	7,840
16	4 9	17 6	2 6	1 9	2 6	$\frac{3}{8}$ B	$\frac{1}{2}$ BB	$\frac{3}{8}$ B	$\frac{3}{8}$ BB	8,512
18	5 0	18 0	2 9	2 0	2 6	$\frac{3}{8}$ B	$\frac{1}{2}$ BB	$\frac{7}{16}$ B	$\frac{3}{4}$ BB	10,080

For properties of B and BB iron plates, see pages 83-4.



FIGURE 65.

These engravings represent the arrangement and setting of the boiler at the trials at Mulhouse, and do not contain the welded and flanged flues, as shown in detail at

* In every case, Low Moor, or equal quality plates, are put over the fire in the flues.
—Abbott & Co.

figure 64. The principal dimensions of the boiler used in the trial are as follows :*

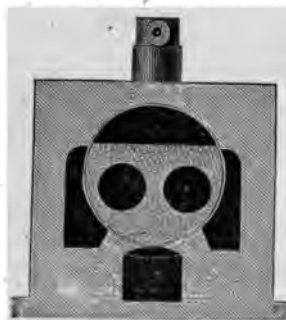


FIGURE 64.

Shell, 6 feet $6\frac{3}{4}$ inches diameter by 25 feet 9 inches long; two flues, each 2 feet $3\frac{5}{10}$ inches diameter. The shell plates were 0.63 inch thick, the end plates 0.748 inch thick, and the flue plates 0.51 inch. The combined width of the fire grates is 4 feet $6\frac{3}{8}$ inches, and their length 5 feet 1 inch; this length includes $6\frac{7}{10}$ inches formed by the parts of the bars resting on iron supports. Taking the effective

length of the grates, therefore, at 4 feet $6\frac{3}{10}$ inches, we get a fire grate area of 20.5 square feet.

TABLE LXXV.

GIVING AN ABSTRACT OF RESULTS OBTAINED IN EVAPORATIVE TESTS WITH THE LANCASHIRE AND FAIRBAIRN BOILERS, AND USING SAARBRUCK COAL.† [MULHOUSE EXPERIMENTS].

	LANCASHIRE BOILER.	FAIRBAIRN BOILER.
Coal consumed per day of eleven hours.....	3,628 lbs.	3,648 lbs.
Net fuel consumed per day of eleven hours.....	3,261 lbs.	3,263 lbs.
Water evaporated per day of eleven hours.....	24,178 lbs.	25,852 lbs.
Equivalent evaporation from and at 212°.....	28,247 lbs.	30,187 lbs.
Actual evaporation per pound of coal.....	6.66 lbs.	7.09 lbs.
Actual evaporation per pound of net fuel.....	7.41 lbs.	7.92 lbs.
Equivalent evaporation from and at 212° per pound of coal.....	7.79 lbs.	8.27 lbs.
Equivalent evaporation from and at 212° per pound of net fuel..	8.66 lbs.	9.25 lbs.
Equivalent evaporation from and at 212° per square foot of heating surface per hour.....	4.19 lbs.	2.70 lbs.
Mean temperature of escaping gases.....	555°	322°
Weight of air supplied per pound of coal burnt.....	18.99 lbs.	14.96 lbs.

* Engineering.

† For analysis and calorific value of Saarbruck coal, see Comb.

The total heating surface of the boilers is 612.5 square feet, divided as follows :

	SQUARE FEET.
Surface of outer shell exposed in side and bottom flues.....	271.03
Surface of internal flues, deducting parts below the grates.....	333.25
Surface at back end of boiler.....	8.22
Total.....	612.50.

The next table gives the sizes of Lancashire boilers, as taken from the catalogue of Abbott & Co., for the first three boilers in the table; the two following are from Tangye Brothers & Holman, London, England :

TABLE LXXVI.
LANCASHIRE BOILERS.

HORSE POWER.	SHELL.		DIAMETER OF FLUE. ^o	DOVE.		THICKNESS AND QUALITY OF PLATES.				APPROX- IMATE WEIGHT.					
	DIAM.	LENGTH		DIAM.	HEIGHT	SHELL	ENDS.	FLUE.	DOVE.						
	FT.	IN.	FT.	IN.	FT.	IN.	INCH.	INCH.	INCH.	INCH.	POUNDS.				
20	5	9	19	0	2	3	2	6	$\frac{7}{16}$ B	$\frac{1}{2}$ BB	$\frac{3}{8}$ B	$\frac{3}{8}$ BB	13,440		
25	5	6	25	0	2	0	2	6	$\frac{7}{16}$ B	$\frac{1}{2}$ BB	$\frac{3}{8}$ B	$\frac{3}{8}$ BB	17,024		
30	6	0	26	0	2	4	2	6	3	0	$\frac{7}{16}$ B	$\frac{1}{2}$ BB	$\frac{3}{8}$ B	$\frac{7}{16}$ BB	20,720
35	6	9	31	0	2	7 $\frac{1}{2}$	3	0	4	1	.....	.....	.....	.....	32,480
40	7	0	34	0	2	9	3	1	4	3	.....	.....	.....	.....	36,400

The following test of a Lancashire boiler shows the evaporative power, rate of combustion, and much other data of interest :

Boiler trials at the South Metropolitan Gas Works, London, England, December 19-21 and January 2-4, 1877-8 :

Diameter of boiler.....	6 feet 6 inches.
Length of boiler.....	25 feet 0 inches.
Diameter of each furnace (2).....	2 feet 3 inches.
Grate surface (whole).....	27.75 square feet.
Grate surface (as bricked up).....	16 square feet.
Total heating surface.....	679 square feet.
Heating surface, deducting lower half of furnaces.....	504 square feet.
Proportion of air space through bars to total grate surface.....	0.2 to 1.

This boiler was set in the usual manner. The products of combustion, after passing to the end of the boiler, returned to near the front end, thence downward to the lower flue and along the bottom to the rear end of the boiler, and thence to the chimney.

The furnaces were fitted with rocking bars, the bars being zigzag instead of straight. The rocking arrangement could not be used on the days in which the grates were bricked up.

	EVAPORATIVE TESTS.	
	WHOLE.	GRATE. PARTIAL.
Duration of trial, hours.....	8.50	11.75
Temperature of feed water.....	50.3°	49.1°
WATER FED INTO THE BOILER.		
Per hour, in pounds.....	1,228	1,288
Per square foot of total heating surface, pounds.....	1.81	1.89
Per pound of coal, pounds (total).....	6.88	9.98
Equivalent evaporation from and at 212° pounds.....	8.0	11.4
Equivalent evaporation from and at 212°, per pound of combustible.....	8.5	11.7
FUEL USED.		
Cefn (South Welsh) coal in both tests: percentage of non-combustible and of water in the fuel.....	6.0	3.0
Total fuel per hour, pounds.....	178.7	129.0
Total fuel per square foot of grate sur- face, pounds.....	6.4	8.1

	GRATE.	
	WHOLE.	PARTIAL.
Total fuel per indicated horse power, pounds.....	3.64	2.79
Condition of fire.....	{ Heavy and black, about 8 inches thick.	{ Light and bright, about 5 inches thick.
Cost of evaporating one gallon of water, cents.....	0.31	0.21
Factor of evaporation.....	1.16	1.14
Rate of transmission of heat (thermal units per square foot of total heat- ing surface per minute), in heat units.....	33.7	34.7
Steam pressure in boiler, above atmos- phere, pounds.....	52.5	55.9
Indicated horse power.....	49.1	46.2
Barometer.....	29.91	30.37
Temperature of the air in boiler house..	47.0°	44.5°
Grate surface, square feet.....	27.75	16.0
Total heating surface, square feet.....	679	679

The Fairbairn boiler, shown in figures 67 and 68, is a modification of the Lancashire boiler, and might be said to

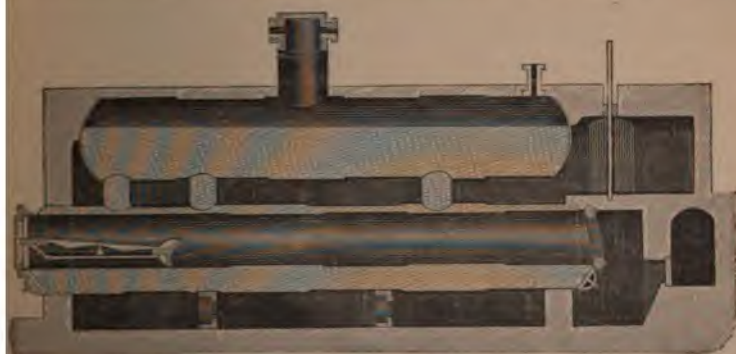


FIGURE 67.

be an internally fired elephant boiler. It consists of three cylindric shells, two of these—each traversed concentrically by an internal flue—being placed side by side at a short

distance apart, while the third is placed above and between them, being joined to them by suitable connecting tubes.

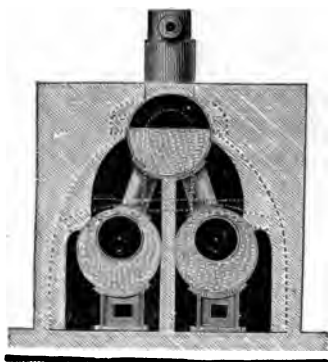


FIGURE 68.

The boiler shown in the above engraving is a representation of the one used in the experiments at Mulhouse, and while possessing all the salient points of the Fairbairn boiler, is slightly modified in design, the two flues in the lower shells being placed eccentrically as shown. *These two lower shells are each 4 feet $1\frac{2}{10}$ inch diameter by 25 feet 9 inches

long, and the flues they contain are 2 feet $3\frac{6}{10}$ inches diameter. The lower cylinders are each connected by three tubes or mouth pieces with the upper cylinder, which is 3 feet $8\frac{2}{10}$ inches in diameter by 22 feet $11\frac{3}{8}$ inches long. The upper cylinder is made of plates $\frac{1}{2}$ inch, and the two lower of plates 0.53 inch thick, while the internal flues are made of 0.51 inch and the ends of 0.71 inch plates.

The grates, which are contained in the internal flues of the lower cylinder, are precisely identical with those of the Lancashire boiler already described. This boiler being one of the three experimented with by the Societe Alsacienne de Constructions Mechaniques, Mulhouse. These were the French or Elephant boiler, described on page 223, the Lancashire boiler, described in this chapter, and the Fairbairn boiler. The heating surface of the latter is 1017.48 square feet, divided as follows :

* Engineering.

	SQUARE FEET.
Surface exposed by the upper cylinder.....	144.88
Surface exposed by the two lower cylinders to the second "run" of gases.....	314.49
Surface exposed by the two lower cylinders to the third "run" of the gases.....	182.96
Surface exposed by six connecting tubes.....	34.04
Surface exposed by two internal flues, deducting surface below grates.....	333.27
Surface exposed at front of upper cylinder.....	3.84
Total.....	1,017.48

It will be seen, on reference to the engraving of this boiler, that the setting is so arranged that, on leaving the internal flues of the lower shells, the gases return to the front end along the sides and bottoms of the two lower cylinders, and thence pass to the chimney between these cylinders and the third one above, a mid-feather wall dividing the flues so that the products of combustion from the two furnaces do not unite until just before entering the chimney.

An abstract of results obtained in the tests at Mulhouse may be found in table LXXV, in comparison with that of the Lancashire boiler.

The *Galloway boiler*, shown in figure 69, is a modification of the Lancashire boiler, in which the two furnaces at the front end unite in one back flue of an irregular oval form. This flue constitutes the chief feature in the "*Galloway boiler*," in which are placed conical water tubes, fixed in an upright position, in such a way as to support the flue and to intercept and break up the flame and heated gases, when passing from the fire grate or furnaces to the chimney. Along the sides of the flues there are also placed several wrought



FIGURE 69.

iron stops or bafflers, which deflect the currents of heated air and cause them to impinge against the tubes, so as to absorb all the available heat possible.

The conical water pipes, or "Galloway tubes," as they are now generally called, present a direct heating surface to the action of the flame or heated gases, and thus effects a great saving in fuel; they also promote rapid circulation of water and thereby maintain that uniform temperature which is so essential to the durability and safety of all steam boilers. Unequal expansion or contraction is avoided and its attendant evils, undue strains and eventual rupture.

Messrs. W. & J. Galloway exhibited three of their boilers, in the British section, at the Centennial exhibition, in which an important improvement over their former designs was shown. This improvement consists in the arching of the bottom part of the oval back flue, by means of which greater facilities are furnished for cleaning and examining the lower part of the boiler when required. A further advantage is also obtained by having the conical tubes all radiating from one center, as shown in the engraving: they are consequently one uniform length and are interchangeable.

These boilers were each seven feet diameter by twenty-eight feet long. The shell was of Bessemer steel plates, three-eighths inch thick, with double riveted longitudinal seams. The two furnaces were each two feet nine and a half inches diameter by seven feet six inches long, made of steel plates, in three rings, flanged and riveted together, as already described on page 260. The main flue contained in it thirty-three conical water tubes, each ten and a half inches diameter at the top, or large end, and five and a half inches diameter at the lower end. These tubes are welded and flanged from one plate, and thus present no joints

her than the flange joints by which they are attached to the flue.

The following data shows the evaporating power of this boiler, as determined at the Centennial exhibition; the trial using anthracite, and the other trial using bituminous coal. Two regular trials were made with each kind of coal—one for economy, the other for capacity :

	ANTHRACITE.	BITUMINOUS.
Pressure of steam above atmosphere..	70.06	70.12
Temperature of steam, average.....	310°	310°
Temperature of uptake, average.....	303°	324.6°
Temperature of feed water, average...	56°	55°
Coal consumed per square foot of grate		
per hour.....	8.87 lbs.	7.27 lbs.
Water evaporated per pound of coal..	8.51 lbs.	9.18 lbs.
Water evaporated per pound of combustible	9.58 lbs.	10.07 lbs.
Water evaporated per hour.....	2,946 lbs.	2,603 lbs.
Water evaporated per square foot of heating surface per hour.....	3.03 lbs.	2.67 lbs.
Percentage of moisture in the steam...	0.22	0.57
Number of pounds of saturated steam evaporated at 70 lbs. from 212°, equivalent to total heat units derived from the fuel—		
Per pound of coal.....	9.94	10.69
Per pound of combustible.....	11.19	11.72
Per square foot of heating surface	3.53	3.11
Horse power, at 12½ square feet.....	77.88	77.88
Horse power, on the basis of 30 lbs. of water actually evaporated per hour, per horse power.....	98.19	86.77

Vertical boilers.—There has been a very great demand in this country, within a few years past, for small internally fired vertical boilers. These are used for furnishing steam

for small engines, pumps, heating, etc. The simplest form

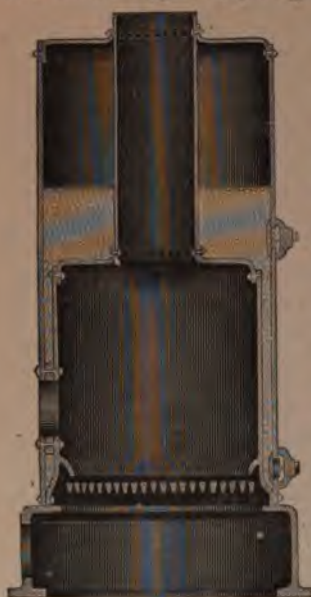


FIGURE 70.

of these boilers is shown in figure 70. When used for heating, where pressures are only five to ten pounds, it is not usually the practice to put in stay bolts or braces; but when used for furnishing steam for small engines or pumps, or for any purpose where the pressures may be anywhere from fifty to seventy-five pounds, the stay bolts and braces should always be put in. Sometimes a ring is put in between the outer shell and the fire box at the bottom, and at other times the fire box is flanged, as shown in the engraving. The writer has made them both ways, but prefers the latter. Each boiler should have

one or more hand holes just above the crown sheet, and at least three in the bottom, as shown in the engraving.

These hand holes are quite essential to inspection and cleaning and should never be omitted. The writer once saw a boiler of this description, in which the space between the fire box and the shell had completely filled with scale, and if the boiler had been used for any purpose in which it would have been necessary to use even a moderate pressure, disastrous results must have certainly followed. Whether the blame could attach to the owner or not, it certainly could to the boiler maker, who was guilty of little less than criminal negligence in not putting them in. The writer has seen what might be called a clever trick in evading this known duty in boiler construction in order to save a few dollars—that is, by the insertion of two or three one

inch or one inch and a quarter pipe plugs. This is not sufficient, and nothing less than a 2×3 hand hole should ever be used, even in the smallest boilers, and as much larger as the circumstances will permit.

The ring around the fire door opening should be preferably of wrought iron, though cast iron is often used. If a ring is to be used at the bottom of the boiler instead of flanging the fire box, as shown in the engraving, it should be of wrought iron *always*.

The following table gives the principal dimensions of vertical flue boilers. The shell being $\frac{1}{4}$ inch thick in all cases, the fire box $\frac{5}{16}$ inch thick, the outside heads $\frac{3}{8}$ inch for all sizes up to 44 inches, inclusive, and $\frac{7}{16}$ inch thick for larger diameters. The inside heads are $\frac{5}{16}$ inch thick up to 40 inches, and $\frac{3}{8}$ inch for the other sizes.

TABLE LXXVII.

PROPORTIONS AND WEIGHTS OF VERTICAL FLUE BOILERS AS SHOWN IN FIGURE 70.

SHELL.		FIRE BOX.		FLUE.		GRATE AREA.	HEATING SURFACE.	HORSE POWER AT 9 FEET.	WEIGHT.
DIAM.	HEIGHT	DIAM.	HEIGHT	DIAM.	AREA.				
INCHES	INCHES	INCHES	INCHES	INCHES	SQ. FT.	SQ. FEET.	SQ. FEET.		POUNDS.
30	60	25	33	9	.44	3.41	24.5	2.7	1,087
32	66	27	36	9	.44	3.98	28.9	3.2	1,236
34	72	29	39	10	.55	4.59	34.0	3.8	1,409
36	78	31	42	11	.66	5.24	39.6	4.4	1,585
38	84	32	45	11	.66	5.59	43.6	4.8	1,777
40	90	34	48	12	.79	6.31	49.9	5.5	2,012
42	96	36	51	12	.79	7.07	55.8	6.2	2,245
44	102	38	54	13	.92	7.85	62.9	7.0	2,473
46	108	39	57	14	1.07	8.36	68.8	7.6	2,786
48	114	41	60	15	1.23	9.17	76.6	8.5	3,036

These weights do not include either the grate or base, but do include stays and braces.

The diameters of the outer shell and for the fire box, as given in the above table, are *inside* measure. The height of the boiler is that from the bottom of the lower joint to the top of the upper head. In regard to this height, if it is found to be inconveniently high, it may be lowered 12 to 18 inches for the lower half of the table without interfering with the heating surface or decreasing the boiler power. The height of the fire box is from the bottom of the boiler to the lower side of the head. The water space for boilers 30 to 36 inches, inclusive, is $2\frac{3}{4}$ inches; from 38 to 44 inches it is $2\frac{1}{2}$ inches, and from 46 to 48 inches it is $3\frac{3}{4}$ inches. The diameter of the flue is inside measure.

In boilers of this class the fire box is the main thing as a matter of course, and ought to be large and roomy. If it were thought advisable, the heights given in the table might be reasonably extended. In the examples given above, the fire boxes have parallel sides; if they were inclined, as shown in figure 71, it would improve the circulation, and add but very little, if anything, to the cost.

The Shapley boiler, as made by the Knowles Steam Pump Works, is shown in sectional elevation in figure 71.

This boiler is made in two sections, the lower section containing the greater part of fire box and the vertical tubes; the latter are situated between the fire box and outside shell, having their lower terminus in two base flues, extending from either side of ash pit entrance to smoke stack at the rear of the boiler. The upper section is principally a reservoir for steam. The fire box extends a short distance into the upper section, and the products of combustion are conveyed through cross tubes, to the vertical tubes as indicated by the arrows, thence downward to the base flues and so to the chimney. The tubes and crown sheet are removed as far from the intense heat of the fire as the size of the boiler will permit; this also insures a large com-



FIGURE 71.

stion chamber, a thing which is always to be secured in
ernally fired boilers whenever possible. The tubes are
(19)

well protected from the action of the fire, and are quite accessible in case they need repairs.

The Baxter boiler—The boiler furnished with the well known Baxter engine, as built by the Colt's Patent Fire Arms Manufacturing Company, is shown in figure 72, which is a representation of the boilers regularly furnished with their engines, with the single exception of their smallest size, or two horse power, which is illustrated in figure 74. Referring to figure 72, it will be seen that all the

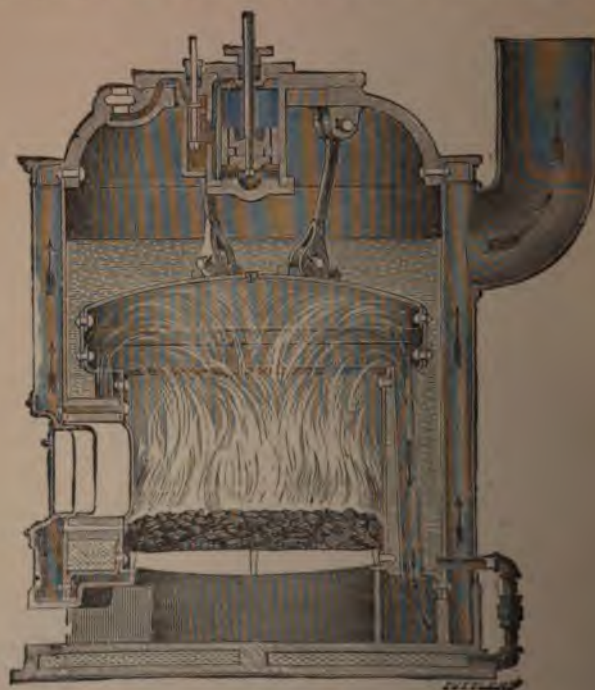


FIGURE 72.

heating surfaces are below the water line. The combustion chamber is large, and of a form to insure economy of fuel. The fire box is provided with descending flues,

passing through the water space and communicating with a jacket surrounding the water space and extending up to the water line of the boiler, so as to leave the dome uncovered and to which the engine is attached, as shown. Figure 73 is a horizontal section showing the arrangement of the descending flues, the furnace door, the grates, and the jacket surrounding the boiler containing the heated products of combustion on their way to the chimney. The design of this boiler is such as to insure a proper circulation of water, hence there is little or no danger of priming.

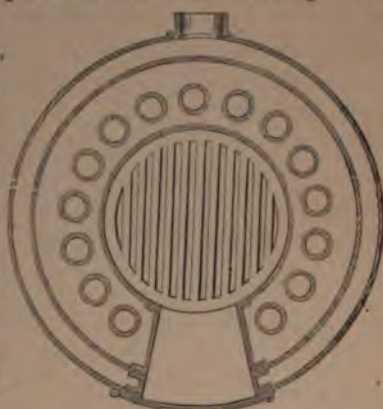


FIGURE 73.

The smallest size, or two horse power, is shown in sectional elevation in figure 74, and differs from the one already described in having no descending flues, as shown in the other engravings, having instead an internal chamber, or fire box, with an annular heating chamber between it and the inside of the boiler.



FIGURE 74.

Vertical tubular boilers—The commonest form of a vertical tubular boiler is shown in figure 75. It does not differ from the vertical flue boiler, already described, except in having tubes instead of flues above

the furnace. This is the form of boiler usually supplied with the numerous small vertical engines now offered in the market. When properly made, it is an economical boiler, and with proper management will be found to be quite durable in service.

The tubes in vertical boilers, especially if short ones are employed, should not be of large diameter. The diameters usually employed are two, two and a half and three



FIGURE 75.

inches. The number of tubes may be such that their aggregate area shall equal one-eighth of the grate area. The following table (LXXVIII) gives the principal proportions of vertical tubular boilers having the same size of fire box as given in table LXXVII, for vertical flue boilers. This is higher than vertical fire boxes are usually made for the diameters given. The writer attaches so much more importance to fire box heating surface than to tube surface that he recommends high fire boxes rather than long tubes, especially as the heating surface proper is that only to the water line and not to the upper limit of the tubes. The height of water carried above the crown sheet in

vertical boilers is scarcely ever more than twelve inches; the value of the tube surface may be easily over estimated by not taking into account the comparatively small portion of the whole surface actually utilized.

TABLE LXXVIII.

PROPORTIONS AND WEIGHTS OF VERTICAL TUBULAR BOILERS, AS SHOWN IN FIGURE 75.

SHELL.		FIRE BOX.		TUBES.		GRATE AREA.	HEATING SURFACE	HORSE POWER AT 12 FT. ⁰	WEIGHT.
DIAM.	HEIGHT	DIAM.	HEIGHT	NO.	DIAM.				
INCHES	INCHES	INCHES	INCHES		INCHES	SQ. FEET.	SQ. FEET.		POUNDS.
30	60	25	33	36	2	3.41	61.2	5.1	1,163
32	66	27	36	42	2	3.98	77.7	6.5	1,367
34	72	29	39	48	2	4.59	95.5	8.0	1,583
36	78	31	42	55	2	5.24	116.7	9.7	1,825
38	84	32	45	36	2½	5.59	109.9	9.2	1,995
40	90	34	48	42	2½	6.31	134.5	11.2	2,301
42	96	36	51	58	2½	7.07	161.4	13.4	2,604
44	102	38	54	53	2½	7.88	187.7	15.6	2,941
46	108	39	57	54	2½	8.30	202.7	16.9	3,195
48	114	41	60	60	2½	9.17	235.4	19.6	3,611
50	120	43	60	66	2½	10.08	277.7	23.1	4,000
52	120	45	60	72	2½	11.04	290.0	24.2	4,225
54	120	46	60	51	3	11.54	266.6	22.2	4,291
56	120	48	60	55	3	12.57	286.0	23.8	4,518
58	120	50	60	60	3	13.64	309.3	25.8	4,815
60	120	52	60	66	3	14.75	335.6	28.0	5,083

These weights do not include the grates, base or fittings of any kind, but do include hand hole plates, stays, braces, etc.

In horizontal tubular boilers the grate area may be made of any size best suited to the fuel to be used and the quantity to be burned. In vertical tubular boilers the grate area is fixed by the diameter of the fire box, and the fuel must be selected with reference to the most economical consumption. Anthracite nut coal or crushed coke

* If the ordinary number of tubes are put in the head, then use 15 as a divisor.

will, in general, be found to give the best results when burned in vertical boilers than if bituminous coal is used, unless the latter is very slowly burned and sparingly fired. It should be broken up into small pieces not larger than a hickory nut, or about the size of anthracite nut.

One of the inconsistencies in rating boiler power by total heating surface is shown by a comparison of the thirty-six and thirty-eight inch boilers in the above table. The fire box in the latter boiler is one inch larger in diameter and three inches higher; the tube area in proportion to the grate is practically the same, yet the larger boiler rates nearly a half horse power less than the smaller one.

In comparing the above table with almost any manufacturer's published list of vertical boilers, the first noticeable thing which will attract the reader's attention will be, doubtless, the small number of tubes for the diameters given. The writer has before him three lists of this kind—all of them, as manufactures, are of very high standing—two of them American and one English. The number of tubes called for in the above table, for a 48 inch boiler = 60, $2\frac{1}{2}$ inches in diameter; one of the American lists for the same diameter has 97, $2\frac{1}{2}$ inch; the other 88, $2\frac{1}{2}$ inch tubes. The English list has 30, $2\frac{1}{2}$ inch tubes.

There is probably no heating surface of so little value as the tubes in a vertical boiler; from half to two-thirds of their length is in the steam space and thus performs no useful service in evaporating water. The value of the remaining half or one-third, as the case may be, is in contact with the water, but, on account of their position with reference to the furnace, and thus presenting no surfaces against which the heated gases can impinge, it is to be regarded as heating surface of the very lowest order.

The most effective heating surface in boilers of this class is that of the fire box; and the tube area should not greatly exceed that necessary for draft, merely. It is bet-

ter to have a large fire box and few tubes, than a small fire box and many tubes. In the table given above, the tube area is fully fifty per cent greater than that necessary for draft, so that, the number of tubes given in the table ought not to be exceeded; deducting one-third from the tabular numbers will give the smallest number of tubes admissible, which is, one-eighth of the grate area. Between these two limits may be considered good if not common practice.

In England, the tube area for vertical boilers is fixed by the grate area; in this country, no account is taken of the grate area, but as many tubes are placed in the head as it will contain. By the latter method it is easy to figure large powers, but it would be a gain to manufacturers and users alike to leave out the surplus tubes and employ a smaller divisor for the rating. It is efficiency and not extent of heating surface that is needed.

The upper end of the vertical tubes, as shown in figure 75, are liable to waste away by being continually heated, and in time will often prove very troublesome. Much of this is due, perhaps, to the too rapid firing before the steam is on the boiler. Many cases of this kind have come within the observation of the writer, and some very curious phenomena, in connection with the wasting of the upper end of the tubes, have been disclosed. To obviate any difficulty of this kind the tubes may be shortened and the products of combustion pass up into a receiving chamber, from



FIGURE 76.

which they may then pass into the chimney, as shown in the sectional elevation in figure 76. By this arrangement in the design of a boiler the tubes are wholly protected by the water, and will outlast those, as shown in the boiler on page 276. The length of the tubes should be such that at least six inches of water should be above them in ordinary steaming. The upper chamber must have depth enough to be able to use an expander in setting the upper ends of the tubes. This upper chamber contracts the steam space and largely reduces the water surface. The engraving does not show the best proportions for a boiler of this kind for rapid steaming; the tubes being too numerous and too long, the upper chamber too large in diameter in proportion to that of the boiler; still it conveys the idea. In cases where these boilers have been used for heating, they have given satisfaction and are well liked.

A modification of the above design is given in figure 77, in which it will be observed that the upper chamber is conical instead of parallel, as in the boiler just described. This design is that of the boilers furnished by the Niles Tool Works, Hamilton, Ohio, with their small engines, from two to twelve horse power. The following table is compiled from their practice. This is an excellent form of boiler and is capable of yielding good evaporative results.

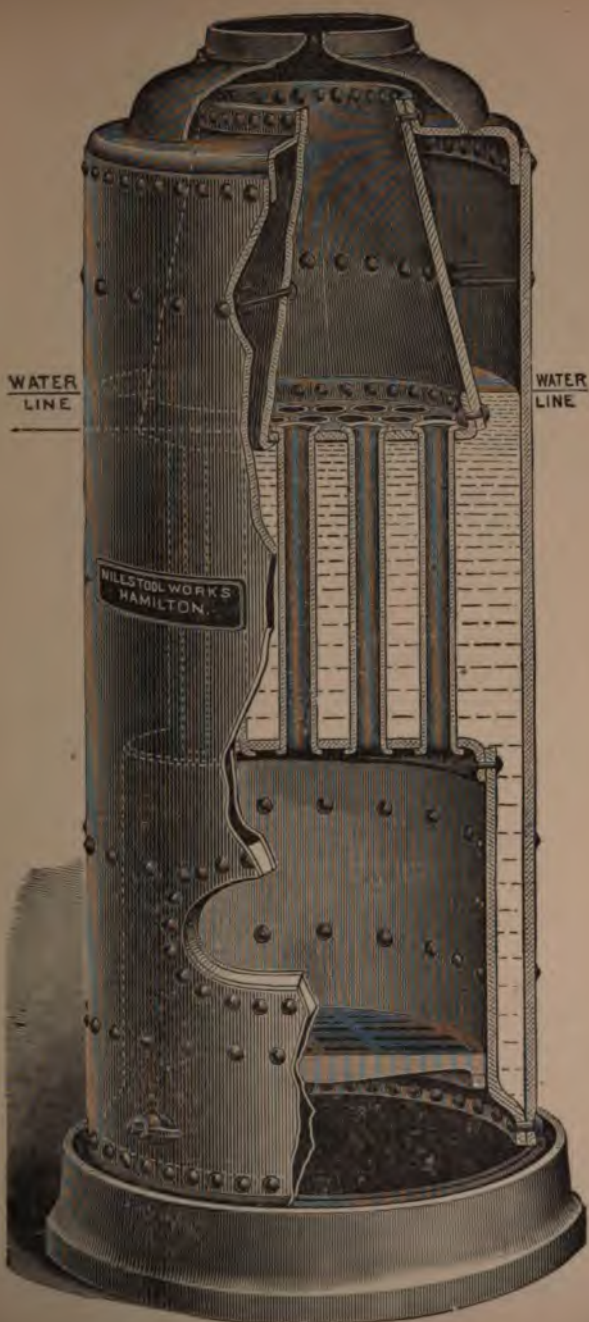


FIGURE 77.

TABLE LXXIX.
PROPORTIONS OF VERTICAL TUBULAR BOILERS, BY
THE NILES TOOL WORKS.

HORSE POWER.	SHELL.		TUBES.	
	DIAMETER.	HEIGHT.	NUMBER.	DIAMETER.
2	24	52	18	2½
4	28	62	27	2½
6	30	66	37	2½
8	33	71	42	2½
10	36	77	55	2½
12	42	80	69	2½

Each horse power in this table is based on 15 square feet of heating surface.

The commonest and at the same time the worst fault of small vertical tubular boilers is that of priming. . There is no doubt that much of this trouble is due to having too many tubes in the boiler, which may and often does have the effect to retard the circulation immediately over the crown sheet. Priming may be induced through other causes, such as bad feed water, sudden reductions in pressure, etc. Whatever may be the cause it is a troublesome and dangerous occurrence, and one which needs to be overcome at any cost. The New York Safety Steam Power Company introduce in their vertical tubular boilers a baffle plate through which all the tubes pass at about the water level. A vertical section of their boiler illustrating this detail of construction is shown in figure 78.

A large tube hangs from the center of this plate nearly to the crown of the furnace and an annular space is left around the outside of the baffle and between it and the circulator sufficient for the easy escape of the steam and

water. The effect of this arrangement is to stop the current of steam and water tending to shoot up between the tubes, and compel it to flow outward and escape between the baffle and circulator, at which point the steam and water separates, most of the water flowing over the circulator, as before described, while the remainder of the water falls on the top of the baffle plate and flows through the tube in its center, thus keeping up a constant current over the center of the crown sheet and among the tubes. It will be observed that the steam



FIGURE 78.

is taken off from the very center of the boiler, and as the steam is delivered at the outer edge of the baffle it must flow inward between and around the tubes on its way to the engine and become dried and slightly super heated.

This improved arrangement not only secures thorough circulation and dry steam, but by its use the operator is enabled to keep as much of the fire surface wetted as he may wish, by simply locating the baffle at the desired point.

Snyder's Vertical Boiler—A novel design for small boilers is shown in figure 79. It is not an internally fired boiler, and does not properly belong to this chapter. It

is manufactured by Mr. Ward B. Snyder, New York city, to supply a popular demand for a small and low priced steam motor. Figure 79 is a sectional view of the



FIGURE 79.

boiler. The letters in the cut indicate spaces as follows: A, dome top or smoke bonnet; B, steam space; C, water space; D, furnace or fire box; E, ash pit.

This boiler consists of a $\frac{1}{4}$ -inch wrought iron lap welded cylinder, with the heads fitted, as shown in the engraving. A tubular stay rod, which also acts as a flue, is secured to the two heads. The engraving shows but one tubular stay; others may be added if thought necessary. For steam yacht boilers the makers recommend from five to ten of these tubes, according to size of main boiler, which serves to keep the main body of water steady, in case of the rolling of the boat.

A number of side tubes are fitted to the shell of this generator, as shown in elevation in figure 80, through which there is a free circulation, throwing continuously a stream of mixed water and steam upon the surface of the water in main boiler, the steam ascending and the water descending, as indicated by the arrow points, while outside and around these tubes there is a free circulation of the heat and abundant room for the combustion of gases.

These side tubes, instead of being fastened in by the use of an expander, are held by bushings threaded inside

and out to fit the taper threads on the outside of the small tubes and the holes in the central shell B which receive them. The stay 2, figure 79, is fastened in the same way to the top and bottom heads. One fact is worthy of notice in reference to putting in boiler tubes in this way, viz, that the tubes and stays must be brought to an absolute fit before the thread of the bushings can be entered or started, consequently they impose no strain upon the boiler of themselves, as is too often the case of ordinary riveted stays.

The whole of the boiler proper is secured to the upper plate, marked 20 in figure 79, and is suspended in the inner casing marked 8, around which is still another casing, marked 7. The air supply for the furnace may be made to enter at the top of the boiler, at 20, and pass down into the ash pit between the casings 7 and 8. This will supply the fire with heated air, thus adding to the economy of fuel and preventing loss of heat by radiation.

The following table gives the principal dimensions of these boilers:

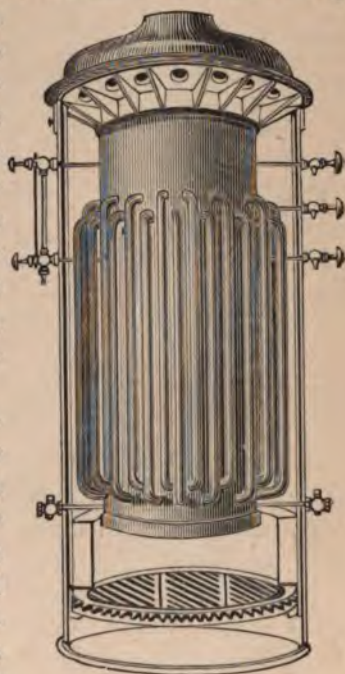


FIGURE 80.

TABLE LXXX.
SNYDER'S VERTICAL BOILERS.

HORSE POWER.	CENTRAL SHELL.			SIDE TUBES.			HEAT- ING SUR- FACE.	BOILER.		WEIGHT COM- PLETE.
	DIAM.	LENGTH	THICK.	NO.	DIAM.	LENGTH		DIAM.	HEIGHT	
	INCH.	INCHES.	INCHES.		INCH.	INCHES.	SQ. FT.	INCH.	INCHES.	POUNDS.
1	10	24	$\frac{5}{16}$	32	$\frac{3}{4}$	16	14	20	50	380
2	12	30	$\frac{5}{16}$	38	$\frac{3}{4}$	24	24	25	61	700
3	15	39	$\frac{5}{16}$	44	$\frac{3}{4}$	27	35	25	68	850
4	15	39	$\frac{5}{16}$	88	$\frac{3}{4}$	50 & 36	48	30	70	1,150
5	15	42	$\frac{5}{16}$	88	$\frac{3}{4}$	50 & 42	58	30	73	1,250
6	15	46	$\frac{5}{16}$	95	$\frac{3}{4}$	60 & 42	69	35	77	1,300
7	16	50	$\frac{5}{16}$	105	$\frac{3}{4}$	60 & 50	83	35	81	1,425

Flynn's Vertical Boiler—A vertical boiler, having many of the good features already recommended, are contained in the design by Mr. Daniel Flynn, Fall River, Massachusetts, and shown in elevation in figures 81 and 82. Its chief peculiarity lies in an enlargement or belt around the waist or middle portion, which is enclosed with and forms a part of the boiler shell, and which, in combination with the provision for returning gases, contributes greatly to the efficiency of the invention.

Figure 81 is a side elevation, showing, on the right hand, the outside of the casing, and on the left, the same broken away, presenting a perpendicular section of the interior arrangements. Figure 82 is a horizontal section of the boiler through XY. In Figure 81, A is the grate. B the fire chamber, and C and C' the surrounding interior and exterior shells. The products of combustion following the direction of the arrows in the engraving, arising from B, first pass through the fire tubes, *aaaa*, into the mixing chamber, E. From this receptacle, the gases have their exit through the large openings, FFF, and after

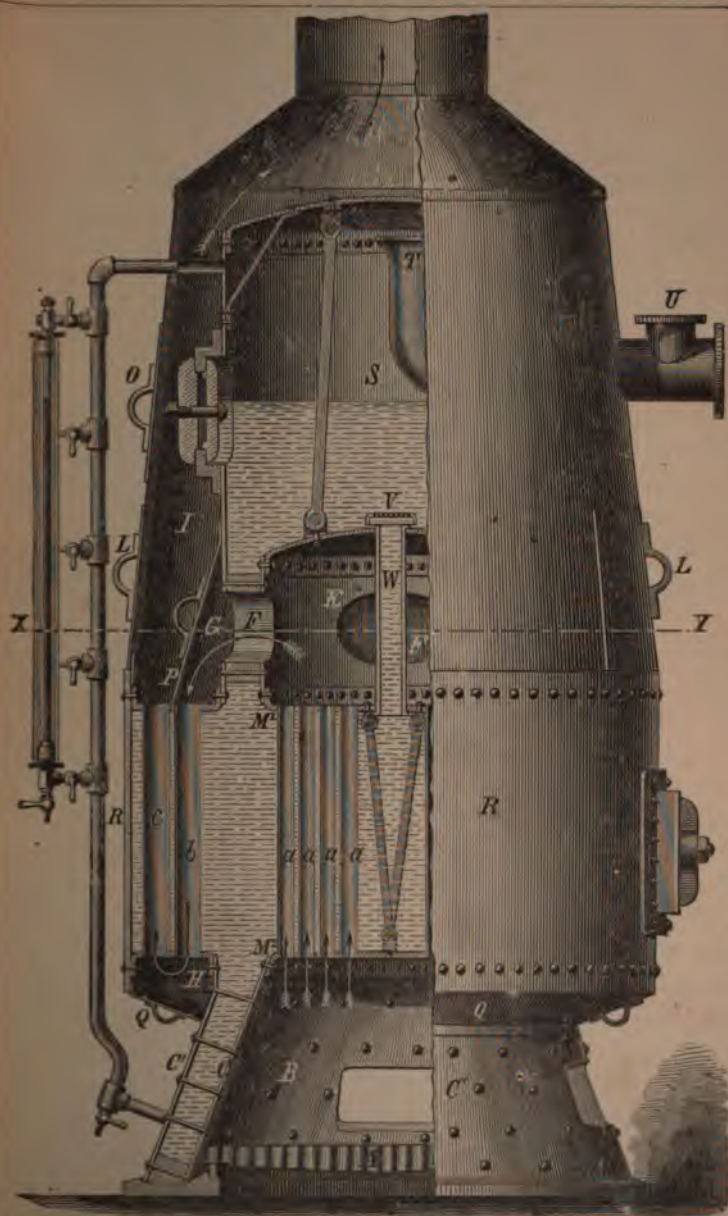


FIGURE 81.

having imparted a portion of their heat in the ordinary manner, are retained by the conical casing, P, which incloses the space, G. They are consequently compelled to descend through the fire tubes, *b*, into an annular chamber, H, which is inclosed in a conical casing, Q. Thence the gases rise through the exterior circle of fire tubes, *c*, and pass

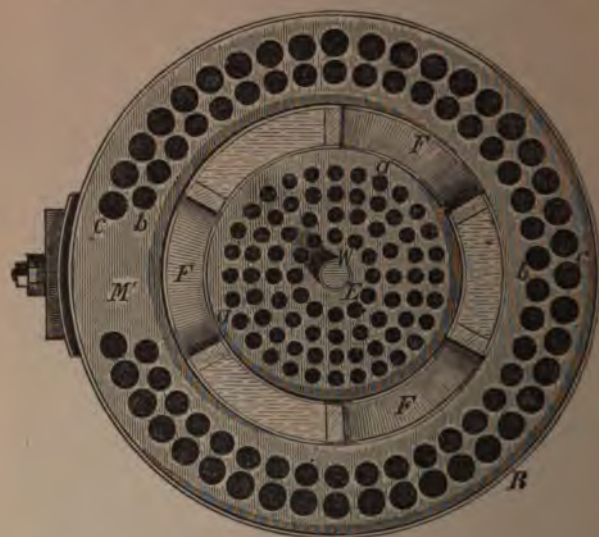


FIGURE 82.

into the large space, I, and finally are discharged through the chimney at the apex, the object of forcing them through this circuitous course being to gain the full benefit of every particle of heat. The particular enlargement above referred to consists of the space between the annular tube sheets, *M*, *M'*, and the outer casing, *R*, in which are the circles of tubes, *b* and *c*.

A special point of advantage, to which attention is directed, is the arrangement of the water spaces. A central chamber, *W*, will be noticed, extending above the crown sheets as far as the mixing chamber, *E*. At this

point, it is reduced in size to a tube, W, which terminates at the bottom of the steam drum, S, its open upper end being surrounded by a perforated cover, V, which prevents a too violent upward motion of the current generated in the lower chamber. In connection with the other water spaces which lie between the systems of tubes, surrounding the fire chamber and occupying the interior of the surrounding casings of the mixing chamber, and finally cover the lower portion of the steam drum; this central chamber adds greatly to the already large separating surface, so that steam may be rapidly disengaged without carrying up water into the steam pipes.

For easy access to all parts of this boiler, for repairs, ample provision has been made. By removing the covering at Q the tubes, *b* and *c*, may be readily cleaned, the refuse falling out at H, by its own weight. The opening of the door at L permits entrance to the space, I, after which, the door, P, being displaced, access may be had to the chamber, G. Through the opening, O, the interior of the steam drum may be reached. At U is the steam pipe, its inner end, T, opening upwards in order to prevent its becoming obstructed through priming of the boiler. To the left of the illustration is the appliance for the test cocks and glass water gauge, which, it is claimed, prevents these appendages from being choked or otherwise rendered inoperative. Its form is plainly shown and needs no special explanation.

The efficiency of this boiler has been amply tested and with successful results. Attention is called to the liberal size of the grate, which, it will be noticed, is of much larger area than could be afforded if the lower portion of the boiler were made on a cylindrical instead of on a conical form. As regards economy, its consumption of fuel is claimed not to exceed two and a half pounds of coal per hour per horse power. In a recent letter to the writer,

Mr. Flynn says that he has obtained an evaporation of 11½ pounds of water per pound of Cumberland coal.

Ample steam space is afforded, which may be increased by making the steam drum of any required height. The outside covering forms a jacket which confines the heated gases around the interior steam generator, so that every available portion of heat contained in the escaping gases is utilized.

Sulter's patent steam boiler—This boiler is of the fire box, fire and water tube variety, and consists of furnace, fire throat, combustion chamber and horizontal return tubular boiler—the whole united to operate together. About the fire box, throat and combustion chamber are water spaces similar to the water legs in ordinary fire box boilers; and circulating pipes are provided from the bottom of combustion chamber to the bottom of the fire box, and from the sides of the horizontal boiler to the side spaces in the fire box. A steam pipe from the steam space in the top of the combustion chamber to the steam space in the horizontal boiler is also provided. The grate bar is somewhat novel, and consists of the ordinary straight single bar depressed to form a fire basket in the center and provided with spaces at the ends to admit air over the fire.

It will be observed that the combustion chamber is so designed that the pressure on the upper and lower sheets tends to tighten the joints of the vertical tubes and thus require no special staying, the circulating pipes acting as supports.

Messrs. Slusser & Sulter, Cincinnati, Ohio, have in use at their works a small boiler, as shown in Figure 83; it is of the following dimensions: Horizontal shell four feet ten inches long by twenty-six inches diameter, with twelve three-inch tubes whole length of shell. Fire box twenty-six inches diameter inside by eighteen inches ver-

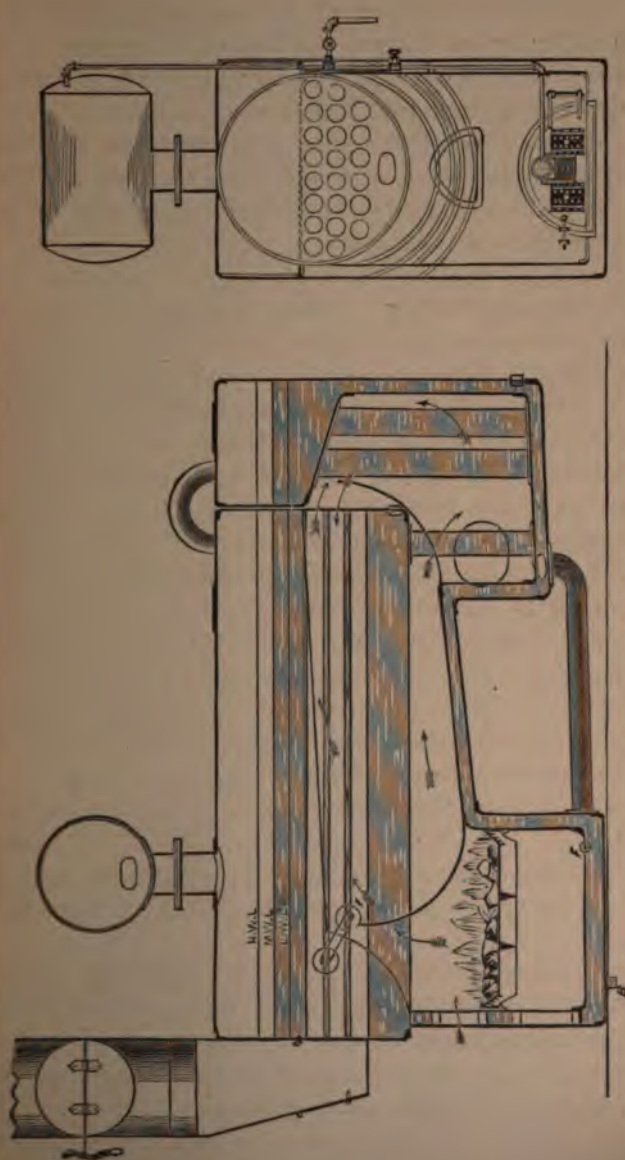


FIGURE 33.

tical depth from bottom of boiler to grate, with two inches water space around the fire chamber and ash pit. Ash pit same diameter as fire box and $12\frac{5}{16}$ inches deep, with a water bottom two inches deep, connected with the water spaces around the fire chamber. The fire throat, which takes the place of the ordinary bridge wall, has a constant width of twenty-six inches and a vertical depth ranging from ten inches at the front end to five inches at the back end; the length of throat parallel with axis of boiler is eighteen inches. The bottom of the throat is an arc of a circle of thirteen inches radius and has a two-inch water space connected with the water spaces of fire box and combustion chamber. The combustion chamber has a diameter inside of twenty-six inches and a vertical height in center of twenty-seven inches. The bottom of the combustion chamber is provided with an entrance hole for examination of the interior and removal of soot and ashes as these may collect in the use of the boiler; this hole is surrounded by an annular water space two inches deep. The water space above the crown plate of combustion chamber and the annular space around the entrance hole are connected by vertical water tubes to secure circulation. The chimney is of sheet iron, twelve inches diameter and about thirty-two feet high from surface of fire grate, connected to front of horizontal section of boiler by the usual breeching.

An evaporative test was made in April, 1878, under the direction of Mr. John W. Hill, consulting engineer in that city.

The coal fired during the trial was Pittsburg, taken from the pile in the boiler room; this was weighed and dumped in charges of 25 pounds. The water was measured to the boiler in charges of 300 pounds, by duplicate tanks connected with suction of feed pump.

Calorimeter tests of the quality of steam produced exhibited a slight super heat; hence, all the water pumped to the boiler was evaporated.

DIMENSIONS OF FURNACE AND BOILER.

Length of horizontal shell.....	4 feet 10 inches.
Diameter of horizontal shell.....	26 inches.
Diameter of fire box inside.....	26 inches.
Diameter of combustion chamber inside.....	26 inches.
Horizontal tubes.....	12, 3 inches.
Vertical tubes.....	6, 3 inches.
Heating surface.....	100 square feet.
Grate surface.....	1.983 square feet.
Cross section of tubes.....	84.82 square inches.
Heating to grate surface.....	50.43
Grate surface to cross section of flues....	3.36
Cross section flues to chimney.....	.75

DATA FROM THE TRIAL.

Duration of trial.....	9 hours.
Temperature of atmosphere.....	73.8°
Temperature of water to boiler.....	146.5°
Pressure by steam gauge (corrected).....	93.93
Water delivered to boiler.....	4965. lbs.
Water entrained.....	None.
Coal fired	594.5 lbs.
Ash and clinker returned.....	37.5 lbs.

RESULTS OF TRIAL.

Steam per pound of coal (from feed).....	8.35 lbs.
Steam per pound of coal from and at 212°.....	9.25 lbs.
Steam per pound of combustible.....	8.906 lbs.
Steam per square foot of heating surface per hour, 5.52 lbs.	
Coal fired per square foot of grate surface per hour.....	33.31 lbs.
Percentage of non-combustible in coal.....	6.3

The boiler is entirely unprotected from loss of heat by radiation, and, according to Mr. J. C. Hoadley's deductions, eleven per cent of the total heat developed was lost in this direction; whilst, had the boiler been well protected by brick side and end walls and overhead arch,

with an air space between the brick-work and surfaces of boiler, the loss by surface radiation would have been reduced to about three per cent, and with other conditions the same, the trial would have developed an evaporation per pound of coal from and at 212° Fahrenheit of $\frac{2.24}{.35} = 10.07$ pounds.

Several years ago Mr. Hill made a series of evaporation trials on five small locomotive fire box boilers, the heating surfaces in which were, for the

First boiler.....	95 sup. feet.
Second boiler.....	85 sup. feet.
Third boiler.....	102 sup. feet.
Fourth boiler.....	84 sup. feet.
Fifth boiler.....	85 sup. feet.

And the evaporation per pound of Pittsburg coal, from and at 212° Fahrenheit, was for the

First boiler.....	6.00 lbs.
Second boiler.....	5.07 lbs.
Third boiler.....	5.54 lbs.
Fourth boiler.....	6.12 lbs.
Fifth boiler.....	6.44 lbs.

Taking the average evaporation of these five boilers at 5.83 pounds, then by this data the Sulter's boiler is capable of doing ($\frac{2.24}{.35} = 1.585$) nearly sixty per cent more work, or furnishing sixty per cent more steam with the same expenditure of coal.

Taken together, the heating surface was less and the grate surface more in the five boilers mentioned than in the Sulter's, and by the ordinary methods of estimating boiler capacity, would be reckoned equal in power to the Sulter's; hence the comparison of economic effects is fair, and exhibits the relative value of the latter boiler in a striking manner.

During the trial the handling of the coal was not the best possible, and the boiler was set in the building in such a manner that the air currents freely circulated around, facilitating the absorption of heat by the atmosphere from the naked surfaces of the arrangement.

Mr. Hill says: "Considering the size of the boiler, I regard the economy obtained as excellent; and am of the opinion that there is merit sufficient in it to justify the construction and trial of similar boilers of larger dimensions."

The question of durability and facility of repair can only be determined by continuous use for a reasonable length of time.

Portable boilers—The demand for a portable engine for agricultural purposes has been increasing for many years

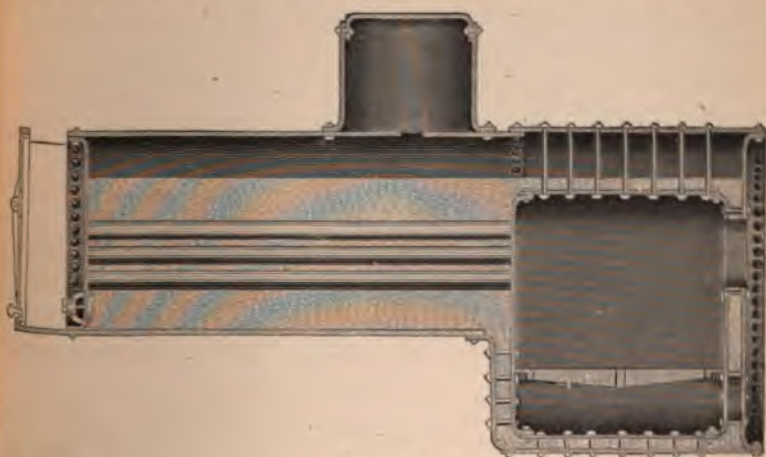


FIGURE 84.

past, and is now a very large and important branch of industry. The boilers supplied with this class of engines are often of some one of the vertical tubular varieties, but more generally a modification of the locomotive type.

Figure 84 is a sectional elevation of a boiler designed by the writer for the Atlas Engine Works, Indianapolis, Ind. There are several hundred of them now in use, and, with proper care, form a very good and serviceable kind of boiler for the purpose intended.

The writer does not wholly approve of the water bottom to the fire box. This was made so originally in order to meet the requirements of Southern planters for use in or around their cotton gins; they were apprehensive that open bottoms, fitted with the ordinary ash pans, might endanger their premises, and require something which seemed to offer a better security against fire.

This boiler is fitted with a fire box, having an arched top and strengthened by means of stay bolts, as shown in the engraving. The reversing of the head at the fire box was done to secure better riveting and calking. This boiler steams rapidly and is very economical in the use of fuel. The following are the principal dimensions, as supplied with portable engines. The latter size is not usually supplied with wheels, but mounted on skids instead. It can be mounted, however, if desired:

TABLE LXXXI.
PRINCIPAL DIMENSIONS OF PORTABLE BOILERS.

	HORSE POWER.		
	8	10	15
Diameter of boiler.....	26 in.	28 in.	30 in.
Length of boiler.....	8 ft.	8 ft. 7 in.	10 ft.
Length of fire box.....	30 in.	30 in.	40 in.
Height of fire box.....	33 in.	34 in.	40 in.
Width of fire box.....	21 in.	23 in.	26 in.
No. of 2½-inch tubes.....	19	27	28
Length of tubes.....	4½ ft.	"	

In some "practical" tests made at the works with very inferior coal as fuel, and feed water at a temperature of 65° Fahrenheit, the eight horse power boiler evaporated twelve cubic feet of water per hour, the ten horse power evaporating fifteen cubic feet in the same time. The evaporation was under a pressure of eighty pounds per square inch. The boilers were in the condition usually delivered to the trade, and the test was as near as possible the same as the firing would have been in the hands of the purchaser, except that it was conducted with a view to ascertain the actual evaporative capacity of the boiler instead of an economy trial.

TABLE LXXXII.

SEMI-PORTABLE BOILERS BY ATLAS ENGINE WORKS.

ENGINE.	HORSE POWER.				
	15	20	25	30	40
Diameter of cylinder	8 in.	9 in.	10 in.	10 in.	12 in.
Length of stroke.....	12 in.	14 in.	16 in.	20 in.	20 in.
Revolutions.....	160	150	140	120	120
Diameter of boiler.....	30 in.	32 in.	36 in.	40 in.	42 in.
Length of boiler	10 ft.	12 ft.	12½ ft.	13 ft.	15 ft. 4 in.
Length of fire box.....	40 in.	54 in.	54 in.	54 in.	54 in.
Height of fire box.	40 in.	45 in.	48 in.	49 in.	50 in.
Width of fire box.....	26 in.	28 in.	32 in.	36 in.	37 in.
No. of 2½ inch tubes.....	28	28	38	49	58
Length of tubes.....	6 ft.	7 ft.	7½ ft.	8 ft.	9 ft.
Diameter of dome.....	16 in.	18 in.	20 in.	24 in.	24 in.
Height of dome.	18 in.	20 in.	22 in.	24 in.	24 in.
Diameter of stack.....	12 in.	12 in.	14 in.	16 in.	20 in.
Length of stack.....	20 ft.	20 ft.	25 ft.	30 ft.	30 ft.

The above table gives the proportions for boilers of the same style, but of larger sizes.

Locomotive boilers—It is not within the scope of the present work to enter into the details of locomotive con-

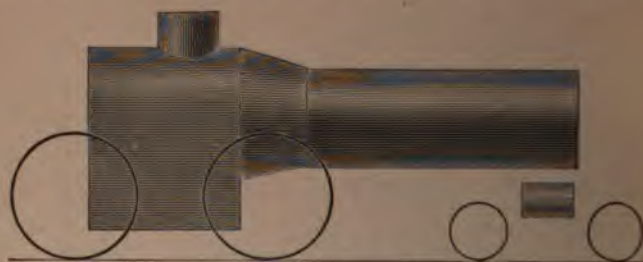


FIGURE 85. CLASS A.

struction, in which the boiler figures so largely. Much that has already been said in regard to boilers in general applies to locomotives. There are also many details of construction, which are peculiar to different builders and to certain roads. These could not be entered into without departing from the original purpose of the writer. It will suffice, perhaps, to give in brief outline the principal dimensions of the locomotive boilers in use on the



FIGURE 86. CLASS B.

Pennsylvania railroad as a guide merely for the proportioning of this kind of boilers for stationary uses. A short description is appended to each engraving to show

the particular service for which each class of engine is intended.

In using the proportions in the table for stationary purposes the size of the boiler is about right for single cylinder engines of the sizes given in the table, if used with natural draft. The combustion of fuel is not as econ-



FIGURE 87. CLASS C. ANTHRACITE.

omical "on the road" as when the rate is lower; which would be the case when used with ordinary chimney or force draft.

Figure 85 is a representation of the boiler used with engines in class A, 17×24 cylinders, which are the ones employed for passenger trains on the main line, except in

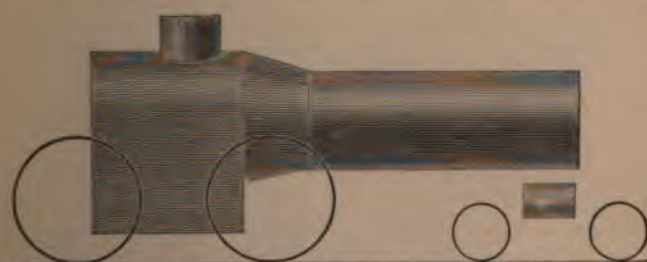


FIGURE 88. CLASS C. BITUMINOUS.

the mountain districts. The principal dimensions are given in table LXXXIII. The shell and fire box of this class of boilers, and, indeed, all the boilers on this road are

wholly of steel; the tubes are, in all cases, of wrought iron, lap welded.

The boilers in class B are somewhat larger than in class A, and supply 18×24 cylinders. These engines are used mainly in the mountainous districts for passenger service.

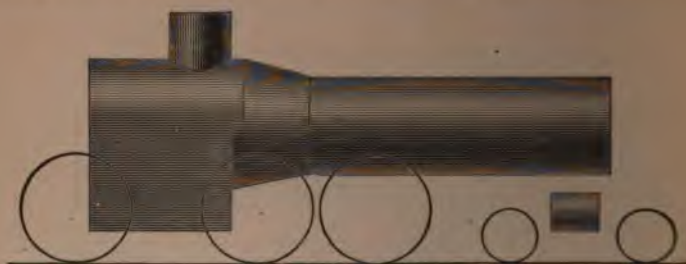


FIGURE 89. CLASS D.

The driving wheels are sixty-two inches diameter as against sixty-eight in class A. The tubes are increased in number and decreased in length over class A; the total heating surface being nearly the same.

There are two styles of boilers for the engines coming within class C. The one represented in figure 87 is for



FIGURE 90. CLASS E.

burning anthracite coal, and the one in figure 88 is for bituminous coal. The cylinders for both styles of boilers are 17×24 . This engine is used for passenger, local and fast freight trains. The number and size of the tubes vary

between these two boilers, a smaller tube being used for the anthracite than for the bituminous coal. The rate of combustion being slower for the anthracite coal, the grate is of larger area, and the heating surface in the fire box increased nearly forty per cent. The tube area is some-



FIGURE 91. CLASS F.

what less than for bituminous coal. The total heating surface divided by the fire grate area is 60.5 for the bituminous, and 39.86 for the anthracite burning boiler. The driving wheels are sixty-two inches diameter.

The engines in class D are intended for ordinary freight service. The tubes are larger in diameter than for any of



FIGURE 92. CLASS G.

the boilers preceding it and of greater length. The fire grate area is also less, the grate bars being but sixty inches in length; the total heating surface in the fire box being ninety-six feet as against one hundred and fifteen in class C, bituminous. The cylinders in engines of this class are

18×22, with six driving wheels, fifty-six inches in diameter.

The engines in class E are intended for freight service in the mountain districts. The cylinders are the same as for class D, viz, 18×22. The drivers are six inches less in diameter. The tubes are longer than in class D, as is also the length of the fire box. The total heating surface in this boiler is greater than any preceding it, except class C, anthracite.

The boilers in class F differ from those already referred to, in the absence of the "camel back." This does not reduce the width of the fire box, but does reduce the height. This engine is used for making up trains and for

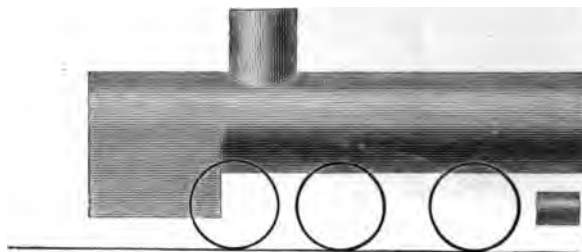


FIGURE 93. CLASS H.

general yard service. The cylinders are 15×18 inches, the driving wheels are 44 inches diameter. The tank is placed over the boiler, as shown.

The engines in class G are used for passenger service on branch lines. The cylinders are 15×22 inches, and have 56-inch driving wheels.

This is a good form of boiler to use for stationary engines. The writer prefers it to what is known as the camel back, as shown in figures 85 to 90. As the rate of combustion is less when used in a building from what it would be "on the road," the fire box might be lengthened if thought necessary.

	CLASS G, PASSENGER ENGINE.	CLASS H, SHIFTING ENGINE.	CLASS I, FREIGHT ENGINE.
Thickness of boiler plates.....	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
Thickness of boiler plates.....	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
Thickness of boiler plates.....	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{16}$
Maximum internal diameter.....	46 $\frac{1}{2}$	47 $\frac{1}{4}$	55 $\frac{3}{4}$
Maximum internal diameter.....	44 $\frac{5}{8}$	44 $\frac{5}{8}$	53 $\frac{3}{8}$
Height from top of rail to.....	70	63 $\frac{1}{2}$	77
Number of tubes.....	130	91	138
Inside diameter of tubes.....	19 $\frac{1}{4}$	23 $\frac{1}{4}$	23 $\frac{1}{4}$
Outside diameter of tubes.....	2	2 $\frac{1}{2}$	2 $\frac{1}{2}$
Length of tubes between.....	115	156 $\frac{3}{4}$	153 $\frac{1}{8}$
Number of internal diameter.....	65.7	69.5	68.1
Length of fire box at bottom.....	54 $\frac{3}{4}$	54.5	96
Width of fire box at bottom.....	35	35	34 $\frac{1}{2}$
Height of crown sheet above.....	52 $\frac{1}{4}$	46 $\frac{1}{2}$	43 $\frac{1}{4}$
Thickness of inside fire box.....	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
Thickness of inside fire box.....	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
Thickness of tube sheets.....	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{8}$
ENGINE { Diameter of cylinder.....	15	15	20
ENGINE { Length of stroke.....	22	22	24
HEATING SURFACE			
External heating surface of boiler.....	652.31 sq. ft.	776.13 sq. ft.	1,158.65 sq. ft.
Internal heating surface of boiler.....	574.0 sq. ft.	699.79 sq. ft.	1,043.28 sq. ft.
Fire area through tubes.....	2.17 sq. ft.	2.51 sq. ft.	3.75 sq. ft.
Fire grate area.....	13.3 sq. ft.	13.2 sq. ft.	23.0 sq. ft.
Heating surface of fire box.....	60.04 sq. ft.	79.11 sq. ft.	100.91 sq. ft.
Total heating surface with tubes.....	721.35 sq. ft.	855.24 sq. ft.	1,259.56 sq. ft.
Total heating surface with grate.....	640.04 sq. ft.	778.90 sq. ft.	1,144.19 sq. ft.
External tube surface divided by.....	9.44	9.80	11.48
Total heating surface divided by.....	54.23	64.79	54.76
Fire grate area divided by.....	6.13	5.25	6.16
Diameter of smoke stack.....	17 in.	15 in.	20 in.
Least sectional area of chimney.....	1.58 sq. ft.	1.23 sq. ft.	2.18 sq. ft.
Fire Grate area divided by.....	8.50	10.8	10.54
Pressure of steam per square inch.....	125 lbs.	125 lbs.	125 lbs.
Effective pressure per square inch.....	100 lbs.	100 lbs.	100 lbs.
Capacity of tank.....	1,600 gals.	2,200 gals.	3,000 gals.
Capacity of coal tank.....	6,500 lbs.	5,000 lbs.	8,000 lbs.

1

The boilers in class H are very similar to those in class F. The boilers are larger in diameter, as are also the diameter of the tubes. The fire box is about ten inches longer. The cylinders are 15×22 inches. The driving wheels are forty-four inches in diameter.



FIGURE 94. CLASS I.

The engines belonging to class I are represented in figure 94. This is the largest and heaviest class of engines in use on this road. The boilers are peculiar in their construction, as seen from the above engraving. These engines are for heavy freight service in the mountain districts. The cylinders are 20×24 inches. The driving wheels are 50 inches in diameter. For the constructive details of this engine and boiler, and for the others already given, the reader is referred to "Engineering," volume 24 or to "The Pennsylvania Railroad," which is a reprint of the articles contained from week to week in "Engineering."

The principal dimensions of these boilers are collated from the tables published in Engineering, and given in table LXXXIII, which may be of very great service to those interested in boilers of this type.

CHAPTER XII.

BOILER SETTING.

Ordinary Boiler Settings—Grates—Force Draft—Resistance of Air in Passing through Pipes—Sizes of Pipes required for Grate Areas—The Jarvis Furnace—The Butman Furnace—The Pierce Furnace.

After deciding which kind of a boiler is best adapted for any particular service, the question of boiler setting should then be carefully considered. There are all sorts of ideas as to how a boiler should be set; many of them good and quite as many more at variance with the actual requirements. It matters little what the particular design of the furnace may be, if it affords complete combustion. The requirements in furnace construction have already been presented in *Combustion of Coal*, to which the reader is referred, particularly to Chapter V, on combustion.

Chapter VI, on air required for furnace combustion.

Chapter VII, on the furnace.

Chapter VIII, on the products of combustion.

A very common form of boiler setting is shown in figure 96, where but little money is to be expended in its erection. It is by no means the ideal furnace; yet it furnishes good evaporative results when properly fired.



FIGURE 95.

The following table gives the ordinary proportions; the letters in the table are those corresponding to dimension lines as given in the engraving bearing the same letters:



FIGURE 96.

TABLE LXXXIV.

PROPORTIONS FOR FLUE AND TUBULAR BOILER SETTINGS.

All dimensions are in inches.

B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	L.	M.	N.	O.	P.	Q.	R.	S.	T.	U.	V.	W.	X.	Y.	Z.
144	25	170	18	48	42	18	44	18		16	18	51	9	13	16	81	13	24	45	13	51	71	74	24
144	25	170	18	48	42	18	44	18		16	20	51	9	13	16	82	13	24	47	13	51	73	75	24
144	25	170	18	48	42	18	44	18		16	20	51	9	13	16	84	13	24	49	13	51	75	76	24
144	21	170	18	52	46	18	44	18		16	20	51	9	13	16	85	13	24	51	13	55	77	77	24
144	21	170	18	52	46	18	44	18		16	20	51	9	13	16	86	13	24	53	13	55	79	78	24
144	21	170	18	52	46	18	44	18		16	20	51	9	13	16	88	13	24	55	13	55	81	79	24
144	21	170	18	52	46	18	44	18		16	20	51	9	13	16	89	13	30	57	13	55	83	80	24
144	17	170	18	60	54	18	44	18		16	20	51	9	13	16	90	13	30	59	13	63	85	81	24
144	13	177	18	60	54	18	44	18		16	20	51	9	13	18	92	18	30	61	18	63	97	82	24
144	13	177	18	60	54	18	44	18		16	20	51	9	13	18	93	18	30	63	18	63	99	83	24
144	1	177	18	72	66	18	44	18		16	20	51	9	13	18	94	18	30	65	18	75	101	84	24
144	1	177	18	72	66	18	44	16		16	20	51	9	13	18	96	18	30	67	18	75	103	85	24
144	1	177	18	72	66	18	44	18		16	20	51	9	13	18	97	18	30	69	18	75	105	86	24

See note below.

The distance given in column D is from the center of the cast iron front to the back end of the rear wall.

The distance E is intended to be that of two bricks. There are sections of the country where bricks will not lay to nine-inch centers. In any such case the thickness



FIGURE 97.

may be varied to suit the size of the bricks. This will apply to columns H, J, P, S and V.

The distance K will vary with the diameter of the mud drum, if one is used. The drum may, in general, be one-third the diameter of the boiler and may extend from outside to outside of the walls and should always be fitted with a man hole. In building the wall, proper allowance must be made for expansion. Figure 97 shows a mud



FIGURE 98.

drum suitable for a single setting and figure 98 for a double setting. Sometimes the mud drum is placed in the direction of the boiler instead of across it; in that case the nozzle is fitted at one end of the drum, the other end passing out through the rear wall.

The distance given in column L is that, when the nozzle is riveted to the second sheet from the rear end, where the sheets have twenty-four inch centers.

The thickness, S and V, are for single walls, but double walls are recommended instead, as being more economical in fuel. The distance W is that from the face of the bridge wall to the inside of the fire front. The grate bars have a "rest" of about one inch at each end on the bridge wall plate and on the bearing bar attached to the fire front. The fronts are intended for separate breechings to be attached to the boiler. When a smoke box is formed by a continuation of the shell, a deeper lining around the fire will be required if the front is brought out "flush" with end of the boiler. This will also change distances D and G as well as W.

The distance, Z, is to the under side of the grate. The engraving shows the grate bars slightly depressed at the back end. This a very common practice in setting grates. The writer does not attach any special importance to it.

The distance from the under side of an externally fired boiler to the top of the grates will vary with the kind of fuel to be burned. For bituminous coal, so far as the writer's observation goes, thirty inches appears to be the best distance.

There are several "batteries" of boilers known to the writer in which the distance is thirty-six inches, and in one instance forty-eight inches. It is not apparent that anything is gained by this extra distance over thirty inches. For semi-bituminous coal the distance may be twenty to twenty-four inches, and for hard anthracite about eighteen inches. These distances may be varied somewhat to suit local conditions.

The furnace walls, as shown in figure 95, are brought in to the boiler sides on the line of the diameter. It is recommended that they be carried up to the water line or just below it, and thus increase the heating surface.

It will be observed that the longitudinal dimensions are for boilers twelve feet long in all cases. In whatever amount the boiler is longer than that distance, columns B, C and D only are changed, unless the rear support to the boiler is to be brought nearer the furnace, in which case the distance, L, will be increased and C decreased.

This setting has a cast iron plate at the back end of the boiler, instead of being arched, as is sometimes the case, and shown in figure 105.

The writer prefers a plate, especially for tubular boilers, as it enables the end of the tubes to be quickly got at for repairs or examination and affords a good light at the same time. No objection exists, however, to the brick arch, and it may be commended for the facility which it affords the return of the gases through the tubes or flues.

The walls are carried up, as shown in the engraving, and filled in over the top of the boiler with some good non-conducting material. There are a number of good non-conductors in the market, which may be used, or a brick arch may be carried over the top of the boiler. This arch may rest upon a thin wooden lining laid over the top of the boiler. Wherever brick work is to come in contact with the shell of the boiler, the joints should be made with fire clay instead of lime mortar; fire clay should also be used with fire brick in the furnace.

Brick should be used throughout in the boiler setting, and is to be preferred to stone for the foundations.

There are localities in which boilers are seldom or never set in the manner shown in figure 96, but have rollers underneath, as shown in figure 105; or rest upon the side walls, the boilers having cast iron lugs riveted to the shell, as shown in figure 61. The writer has fitted them in each of the styles indicated, but prefers the mud drum, either as shown, or passing out through the rear wall.

The grate surface is composed alternately of solid metal and free spaces in about equal areas, or, perhaps, the solid metal slightly exceeds the spaces. The grates should have depth instead of width for the needed strength. It is customary to make the grates of cast iron, though bars of $\frac{1}{2}$ inch or inch and a quarter square iron are often used. For burning anthracite coal a grate made of wrought iron tubes, through which the feed water is made to pass, has been used with good results. A modification of this grate is frequently applied to locomotives.

The ordinary grate bar is too well known to need any description. Figure 99 is an engraving of a grate bar made by Albright & Stroh, Mauch Chunk, Pa. This grate



FIGURE 99.

bar may be used with coal, wood or sawdust, and presents more free space than is usual for grates of this class; it is of light weight, and after a trial it has been found to withstand warping in heavy firing.

The clearing of fires by means of slice bars and hooks is a very difficult and exhausting kind of labor, especially if the grates are of any considerable length. The radiant heat from an open furnace door during the hot summer months is very trying, and none but experienced firemen, as a rule, can stand it.

Ryder's reciprocal grate bars—Figure 100 is an engraving of a grate bar manufactured by Mr. J. F. Montgomery, Taunton, Mass., and is known as Ryder's patent reciprocal grate bar, which was designed to overcome this laborious and difficult operation. These bars are simple in construction, and consist of a series of movable and stationary bars. The movable bars (every other one being

stationary) are moved backward and forward several inches by a lever in front of the boiler, through the ash pit door. The movable bars resting on friction rolls are raised above the stationary bars a little, and have a corrugated surface for friction, which thoroughly disturbs the coal, destroys the clinkers and removes all the ashes, thus opening up a thorough and uniform draft over the entire

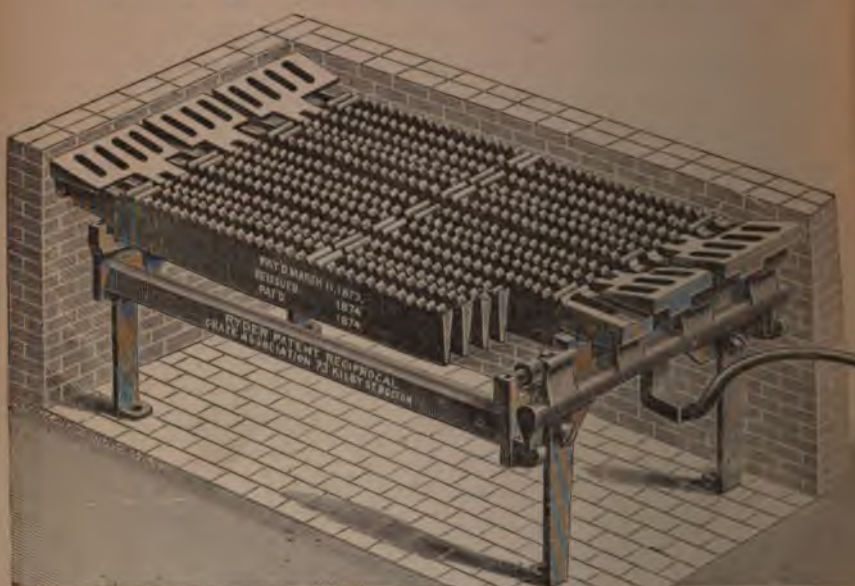


FIGURE 100.

fire surface. By the uniformity of draft and ventilation thus gained, a more perfect combustion of all the gases is obtained.

Steamship engineers and firemen of long experience sailing out of New York and Boston, and those who are running stationary engines and boilers with these bars, report excellent results in the economy of coal, and that an easy generation and uniform pressure of steam is obtained with light fires—firing often with little coal at a time.

The bars should be worked as often as appears necessary to keep the fire clear from ashes and clinkers. The dampers in the flues should be kept well closed, in order to intensify the heat and retain it in contact with the heating surface of the boiler and tubes, instead of rapidly forcing it through them by strong draft, and out of the smoke stack or chimney, with the gases of the coal half consumed, thus wasting nearly one-half the value of the coal.

Keeping the damper closed as much as possible is a good practice at all times. The writer has referred to it once or twice previously in this book.

It is claimed that the reciprocal grate bars develop a new and successful method for the ventilation of fires, as they produce a level surface of coal over the entire grate, ensuring, by the reciprocal action, a uniform or equal consumption of coal; that the bars will not warp or crook; that with three vibrations of the lever, more execution can be performed in the ventilation and cleaning of the fire, than by the use of the poker or slice bar in one hour's time; that a better fire can be obtained, with less draft back of the bridge wall, less fuel and less labor than with any other bars in use, and no loss (but a gain) in steam, while cleaning fires, as the fire doors are never open while cleaning them.

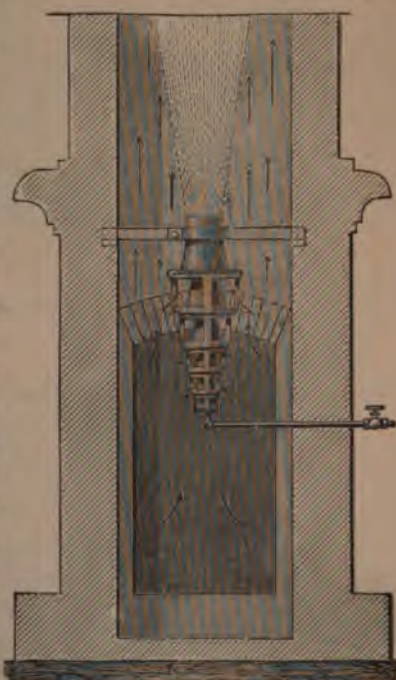


FIGURE 101.

Force draft—In case the draft should be deficient or sluggish, a steam jet or blast nozzle may be used with advantage, something like the one shown in figure 101, and

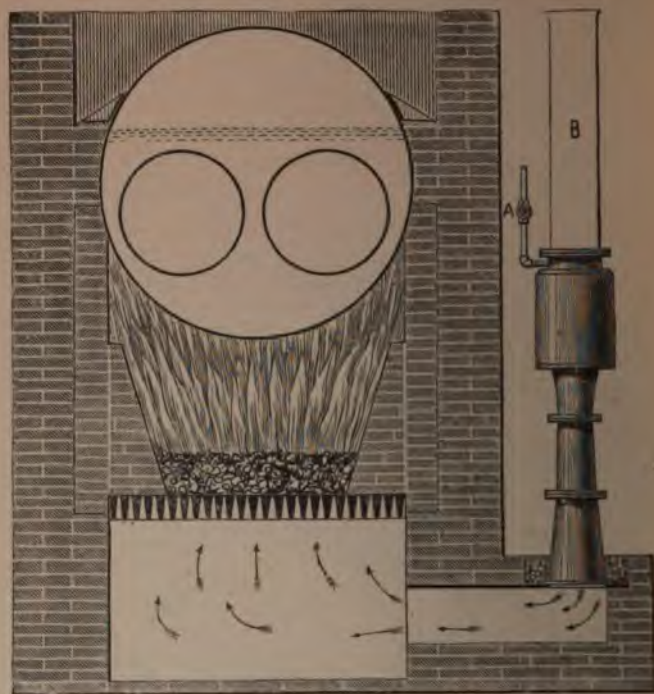


FIGURE 102.

placed in the interior and at the base of the chimney, as shown. This is not equal in efficiency to the forcing of the air under the grates. This usually requires some special adaptation of the apparatus to the ash pit or furnace and is not so easily or cheaply applied, but in the "long run" there is economy by so attaching it, if it is to be a permanent fixture. Figure 102 represents one form of apparatus for a force draft, as designed by Schutte &

ring, Philadelphia, Pa. Figures 101 and 103 are also of the same firm.

When the blower is attached below the grates, as shown in figures 102 and 103, the ash pit must be fitted with a fitting door, that the pressure of the air be compelled

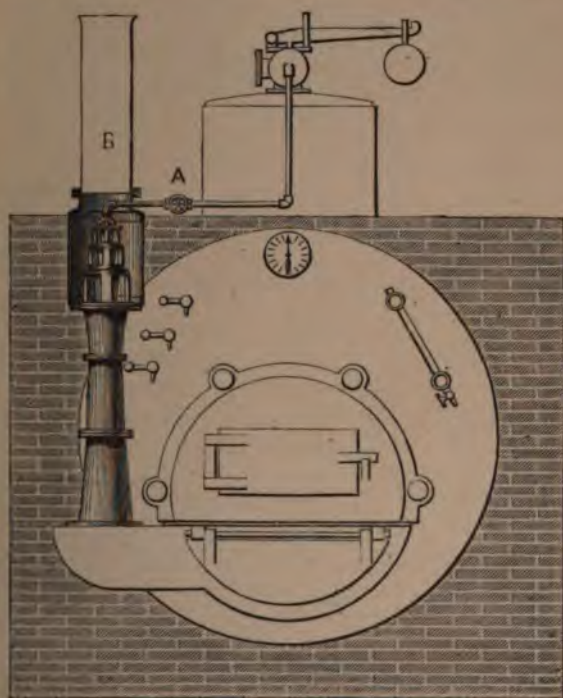


FIGURE 103.

pass up through the fire, instead of forcing its way into the fire room. By the use of a force draft economy of fuel is attained by a more perfect combustion, and will often permit the use of a refuse fuel which could not be burned in an ordinary fire. It also permits the use of a lower and less expensive chimney, which becomes simply an exit for escaping gases. The quantity of air to be admitted to

the fire may be adjusted by means of the valve in the steam pipe at A, the supply of air being admitted through the pipe B. Figure 103 shows the application of the blower to a Cornish boiler.

This firm make four sizes of these blowers, with capacities as follows:

TABLE LXXXV.
STEAM JET BLOWERS FOR BOILER FURNACES, BY SCHUTTE AND
GOEHRING.

SIZE. NO.	CAPACITY.		DIAMETER OF STEAM PIPE.	DIAMETER OF AIR DISCHARGE AND INLET.
	AIR REQUIRED PER HOUR, IN CUBIC FEET.	COAL CONSUMED PER HOUR, IN POUNDS.		
1	30,000	150	$\frac{1}{2}$ inch.	6 inch.
2	60,000	300	$\frac{3}{8}$ inch.	8 inch.
3	120,000	600	1 inch.	10 inches.
4	200,000	1,200	1 inch.	14 inches.

A fan blower is often used for the purpose of supplying air to the ash pit, and serves a good purpose. The only objection to such an arrangement is, that it must be actuated by moving machinery, which is not always at hand; but whenever it is convenient to make suitable attachments it may be used with advantage. Blast gates should be used in all cases and inserted in the blast pipe at any point most convenient for adjustment. When two or more boilers are placed in the same setting, there should be a branch pipe and gate for each boiler. The sizes of blast pipes required, as given below, are for one furnace; where two or more are connected and supplied from one main pipe, its size can be obtained by reference to table LXXXVII. The following data is from the catalogue of Mr. B. F. Sturtevant, Boston, Mass.:

TABLE LXXXVI.

SHOWING DIAMETER OF PIPES REQUIRED FOR SUPPLYING AIR TO
BOILER FURNACES.

NO. OF SQUARE FEET OF GRATE SURFACE.	CUBIC FEET OF AIR TO BE SUPPLIED PER MINUTE.	DIAMETER OF BLAST PIPE REQUIRED, IN INCHES.	NO. OF SQUARE FEET OF GRATE SURFACE.	CUBIC FEET OF AIR TO BE SUPPLIED PER MINUTE.	DIAMETER OF BLAST PIPE REQUIRED, IN INCHES.
1	125	3 $\frac{1}{4}$	8	1,000	8 $\frac{1}{2}$
2	250	4 $\frac{1}{4}$	9	1,125	9
3	375	5 $\frac{1}{4}$	10	1,250	9 $\frac{1}{4}$
4	500	6 $\frac{1}{2}$	12	1,500	10
5	625	7	15	1,875	11
6	750	7 $\frac{1}{2}$	20	2 500	12 $\frac{1}{4}$
7	875	8	25	3,125	13 $\frac{1}{2}$

Mr. Sturtevant has given this subject a great deal of attention for many years, and has made many and costly experiments to determine the frictional resistance of air in passing through long tubes or pipes. The following table was calculated for the use of those putting up blast pipes, who, knowing little or nothing of the frictional resistance of the air, are apt to think that because the combined area of four 6-inch pipes is the same as one 12-inch pipe, that the four pipes will convey the same quantity of air, with the same ease and freedom, that the 12-inch will; whereas it actually does take 5.7—almost six 6-inch pipes. Again, sixteen 3-inch pipes have the combined area of one 12-inch pipe, but in actual practice it takes just thirty-two 3-inch pipes to do the work of one 12-inch. This is due to the excess of friction for every cubic foot of air in the small pipes over that in the large:

TABLE LXXXVII.
TABLE FOR EQUALIZING THE DIAMETER OF PIPES.
B. F. Sutcliffe.

DIAMETER OF MAIN PIPE, IN INCHES.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1															
2	5.7														
3	16	2.7													
4	32	5.7	2												
5	56	9.8	3.6	1.5											
6	88	16	5.7	2.8	1.6										
7	129	23	8.3	4.1	2.3	1.5									
8	180	32	12	5.7	3.2	2.1	1.4								
9	244	42	16	7.6	4.3	2.8	1.9	1.3							
10	317	56	20	9.9	5.7	3.6	2.4	1.7	1.3						
11	402	71	26	12	7.0	4.5	3.1	2.2	1.7	1.3					
12	501	88	32	16	9.0	5.7	3.8	2.8	2.0	1.6	1.2				
13	613	107	39	19	11	6.9	4.7	3.4	2.5	1.9	1.5	1.2			
14	737	129	47	23	13	8.3	5.7	4.1	3.0	2.3	1.8	1.5	1.2	1.4	
15	876	152	56	27	16	9.9	6.7	4.8	3.6	2.8	2.2	1.8	1.5	1.2	1.5

The large figures at the top of each column give the diameters in inches of the branch pipes. The figure

the intersection of the horizontal line with the vertical give the number of pipes, of the diameter given at the top of the column, that will be equal in capacity for conveying air to one given opposite in the first column.

The Jarvis furnace—This improved design in furnaces for steam boilers is that of Mr. K. M. Jarvis, Peabody, Mass., and shown in longitudinal section in figure 104. The object Mr. Jarvis had in view in working out this design was, to take advantage of the quantity of heat escaping from the ordinary furnace and compel it to perform a useful service, by heating the air required to complete the combustion of the fuel and gases evolved during the process of combustion.

In order to accomplish this he utilizes the bridge wall and the back of the furnace, as well as the side walls, for the heating of the air to be discharged into the combustion chamber, hence the greater portion of the side walls are made double. By this arrangement in the construction, the air is delivered to the column of gases freed by the combustion of the coal, through the bottom and sides of the combustion chamber, the heated air acting to reduce the temperature of the gas much less than cold air, thus permitting the oxygen of the heated air to mingle with the gas at a temperature nearer that of ignition, and by this means making the combustion more thorough while the gases are under the boiler and where the greatest heat is needed.

The boiler may be either flue or tubular; the distance from the under side of the boiler to the grate may vary within reasonable limits, and may be from twenty-four to thirty inches. The grates may be of any of the common or improved forms now in the market, and the furnace arranged for either slow or quick combustion. Back of the bridge wall, G, is an open space, C, covered from

side to side with a perforated cast iron plate, shown at O in the engraving; through these perforations passes heated air discharged from flues built in the wall or in the bottom of the furnace. The object in the introduction of this heated air is to mingle with the carbonic oxide gas while it is at a high temperature, and thus supply the oxygen needed to again convert it into carbonic acid gas, and thus render the combustion complete. The same thing may be

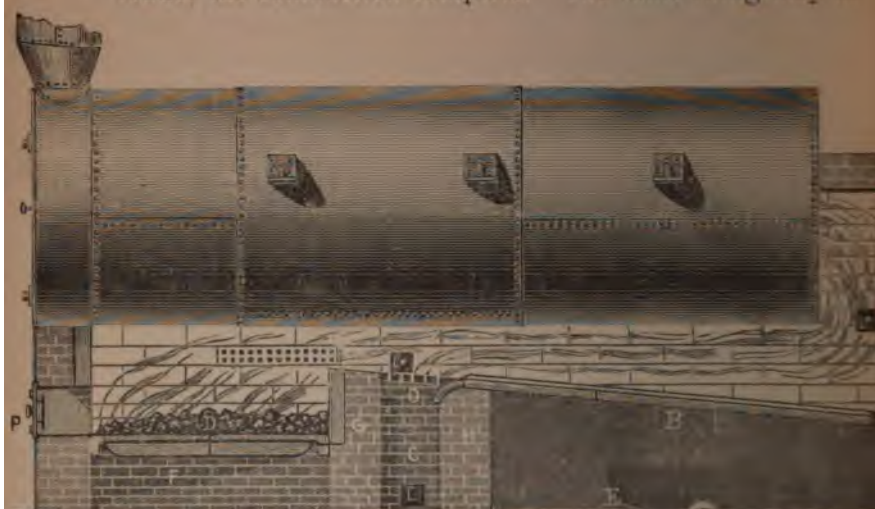


FIGURE 104.

also secured, and is in part assisted, by the openings in the side walls, as shown in the engraving. These hollow walls also perform a useful service in preventing radiation. The details of this furnace are very carefully worked out and are yielding excellent results.

The combustion of peat and lignite is one which will be of considerable importance in the far west, and in some of the northern states. The application of this furnace to the burning of peat has been attended with very successful results. Peat freshly dug from a marsh is mixed with



one-fourth its bulk of small bituminous coal and thrown on the fire, and within a few minutes the gas flames begin to form on the flue openings, and presently the entire furnace is filled with flame, showing a practical gasification of the peat and a perfect combustion of the gases. No blower is needed, as the streams of hot air thrown on the fire create a good draught, and effectively consume the peat and with good results in steam power.

TABLE LXXXVIII.

DESIGNATION OF EXPERIMENTS.	DECEMBER 17 TO 23, OLD SETTING, EIGHT BOILERS.	MARCH 23 TO 31, JARVIS SETTING, SIX BOILERS.
Duration of test.....	6 days and nights.	6 days and nights.
Pressure of steam.....	63	68
Temperature of feed water, in degrees.....	78	82
Amount of water evaporated at temperature, in pounds.....	1,278,682	1,268,880
Amount of coal consumed, in pounds.....	(soft coal, 151,060)	(soft coal, 44,329 screenings, 114,190 158,519)
Amount of ashes.....	19,040	15,698
Amount of combustible, in pounds.....	132,020	142,821
Pounds of water evaporated per pound of coal, at temperature of feed.....	8.46	8.00
Pounds of water evaporated per pound of combustible, at temperature of feed.....	9.69	8.92
Pounds of water evaporated per pound of coal, at 212° ..	9.93	9.32
Pounds of water evaporated per pound of combustible, at 212° ..	11.36	10.39
Pounds of water evaporated for one dollar's worth of fuel	4,742	6,803
Cost of fuel consumed in time run ^a	\$269.60	\$183.40
Gain in economy, in favor of Jarvis setting.....	.....	30 per cent.
Gain in capacity, in favor of Jarvis setting.....	.....	25 per cent.

^aBorden Cumberland coal, four dollars per long ton, delivered in Fall River. New York Cargo screenings, two dollars and thirteen cents per long ton, delivered in Fall River.

The above tests in evaporation were made at the American Linen Company, Fall River, Mass., under the following circumstances: eight 6-foot tubular boilers, running one-half of the mill, were tested, by weighing the water and coal for one week, night and day. The fuel used was Borden Cumberland coal. The boilers were then reset with the Jarvis patent furnace and tested again for the same time. The fuel used on the last test was a mixture of screenings and soft coal, burned without a blower. It only required six boilers, after the resetting, to do the same work that before required eight.

This system of boiler setting is already in extensive use, and, in making it possible to burn peat with economy, will do much to utilize our vast stores of peaty fuel, and tend to cheapen the cost of steam power.

The Butman furnace—This improvement over the old style of setting steam boilers is the invention of Mr. T. R. Butman of Dayton, Ohio. The basis upon which the inventor rests his claims for success are,

1. The utilizing of the waste heat from the chimney, by furnishing a hot blast to the furnace.
2. The supply of the proper amount of heated air directly to and in contact with the hydrocarbon gases at the moment they are evolved from the coal.
3. A complete and perfect combustion of the products of distillation at the surface of the coal, resulting in a large volume of highly heated transparent gases flowing off in contact with the boiler.
4. Such an arrangement of the furnace walls and passages that the heated products of combustion are equally distributed to the surface of the boiler, causing a thorough absorption of the heat by the water, and also preventing any local concentration to burn the metal.

5. Because of the perfect combustion of the gases and carbon of the coal in the furnace. All smoke is positively prevented.

6. Owing to the peculiar manner in which the combustion is effected, all intense local heating of the brick walls and linings of the furnace are prevented, thereby ensuring great durability and a minimum cost for repairs.

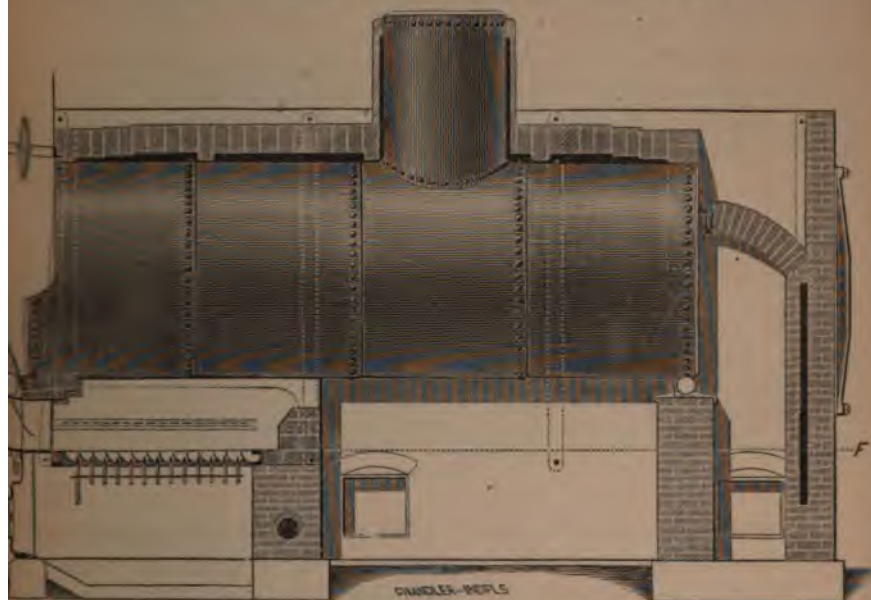


FIGURE 105.

A longitudinal sectional elevation of the furnace is shown in figure 105. It will be observed that it does not, as shown in longitudinal section, materially differ from the ordinary setting in the main essentials. The boiler rests upon the front in the usual manner, and is supported at the rear end on a concave roller, which fits the shell of the boiler and is thus free to roll on a cast iron plate, having a similar curve and which is securely fastened to the rear

wall. The brick work is so designed that it forms a covering over the top of the boiler and coming in contact with it at each end only. Referring to figure 105, it will be seen that there are (in this particular case) three pendants from the overhanging arch, which nearly but not quite touch the top of the boiler. These pendants continue around the top of the boiler and extend down to a short distance below the water line, forming thereby a series of small

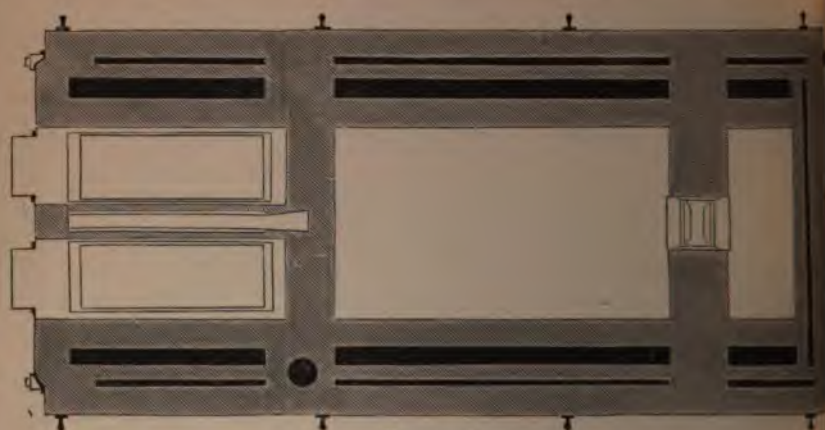


FIGURE 106.

compartments over the top of the boiler—the object of these pendants being to prevent a circulation of heated gases over the top and thus compelling them to flow along the sides of the boiler below the water line, yet, at the same time, allowing the upper portion to be jacketed with hot gases having a temperature scarcely, if ever, greater than 500° Fahrenheit.

A foundation plan of a single boiler setting is shown in figure 106. This shows the hollow walls to prevent radiation, and will be referred to again in connection with figure 107. This plan shows the section at the line F, in figure 105.

A horizontal section through the walls at the center of the boiler, is shown in figure 107. The distance from the side of the boiler to the inside line of fire brick at A is about three inches and gradually increases to the point B, then contracts again to C and thence to D, where the distance is a little greater than at A. These distances from the boiler to the walls at the points B, C, D, will depend upon the diameter and length of the boiler. The

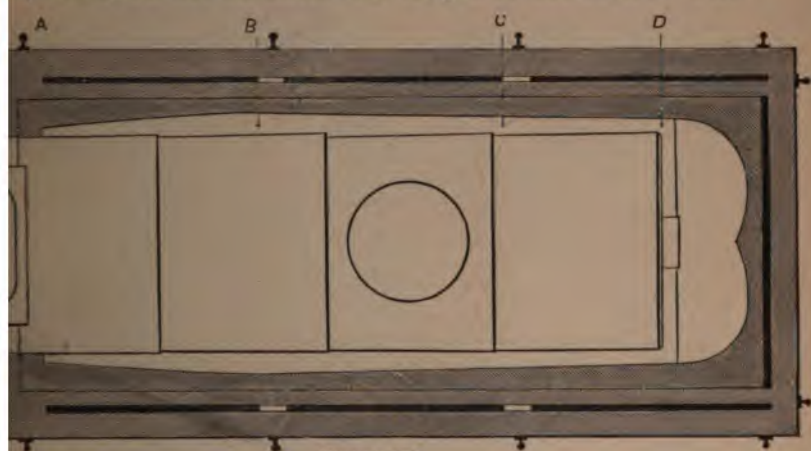


FIGURE 107.

end wall is curved in order to prevent the forming of an eddy of gases at that point and to facilitate the flow of gases into the tubes or flues.

The enlargement of the furnace at B, which is directly opposite the bridge wall at the rear end of grates, is for the purpose of forming a combustion chamber and which is better represented in figure 109. From this point to the rear end of the boiler the walls gradually contract in all directions toward the shell of the boiler and thus compel the escaping gases to come in closer contact by reason of the contracted area between the boiler and the walls of the furnace. Mr. Butman claims that by this arrangement he

prevents the bad effects of the localization of an intense heat at or near the furnace and secures a more uniform distribution of heat along the whole under surface and sides of the shell.

The walls are built with air spaces, as shown, to prevent radiation of heat. The outer wall and the furnace lining are separately laid up, so that the latter may be renewed, if necessary, without disturbing the outside walls.

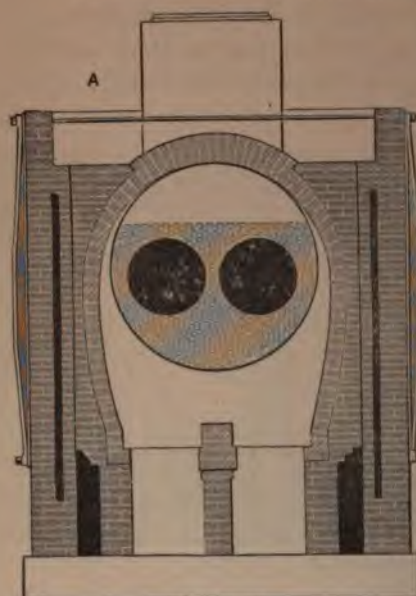


FIGURE 108.

A transverse section of the furnace and side walls at the line A in figure 107 is shown in figure 108. The arch, it will be seen, touches the top of the boiler and then gradually enlarges until it has passed the center of the boiler, when the sides contract to the width of the grate.

Figure 109 represents a transverse section, on the line B in figure 107, and is that portion of the furnace known as the combustion chamber. The position of grates is clearly shown, and attention is directed to the peculiarity of their setting. It will be seen that a wall extends from the foundation up through the ash pit to a distance of about eight inches above the grates, and over this central wall is placed a cast iron box, protected by fire brick from the intense heat of the furnace. This cast iron box has a series of slits along each side of its lower edge. The object of this box is to form a receptacle for the heated air forced

into it by means of the blower, shown on the outside of the furnace and marked F. The air is forced out through these horizontal slits in a thin sheet on each side of the center wall and at a distance of two to four inches above the surface of the fire. The object of these jets of highly heated air in the furnace is to supply the products of combustion with a fresh supply of oxygen in case it should be needed. In the combustion of coal on a grate the air coming up through the fire from underneath, carbonic acid gas is formed as the product of perfect combustion, but in passing up through the fire the highly heated carbon above it abstracts from the molecule of carbonic acid gas an atom of oxygen, and two molecules of carbonic oxide gas are formed, which renders the originally perfect combustion incomplete, and thereby lowering the temperature of the furnace not only, but allowing much of the carbon to escape unburned. If, while the carbonic oxide gas is

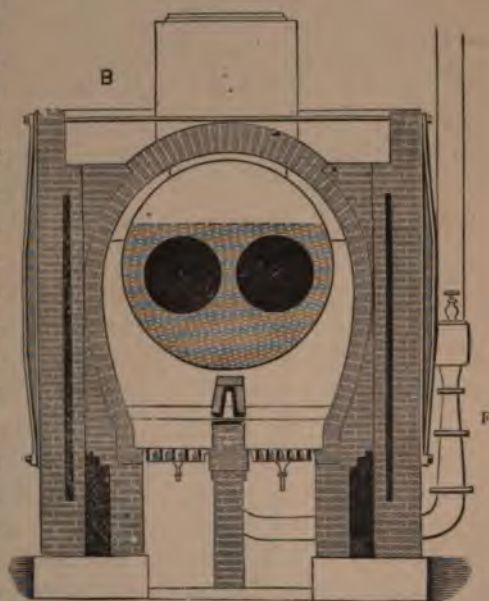


FIGURE 109.

still in the furnace, and at a high temperature, it comes in contact with a fresh supply of oxygen, it ignites and is again converted into carbonic acid gas, which renders the combustion complete, and a great saving in fuel is effected.

The action of the blast, through these side jets, is to prevent the localization of an intense heat underneath the

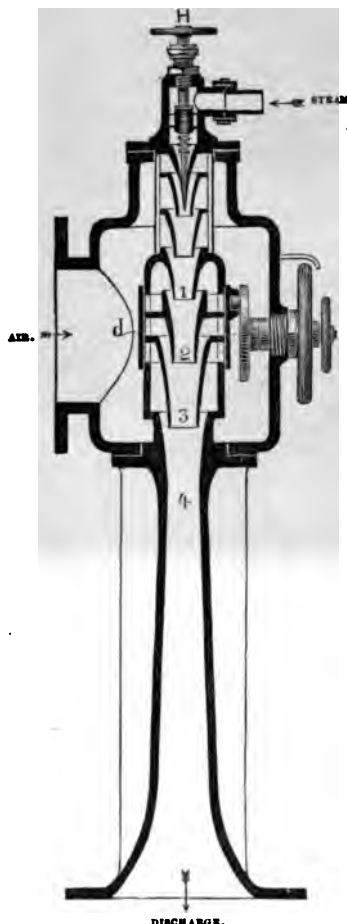


FIGURE 110.

boiler at the furnace, and to carry it along the sides, and distributing it over a greater area, and promoting a current of hot gases along the sides of the boiler instead of confining it along the bottom, as is generally the case in the ordinary settings.

The forcing of the air into the cast iron box in the furnace is accomplished by means of an injector, shown in figure 110, and is from the designs of Messrs. Schutte & Goehring.

In this jet blower, the inducing current is a jet of steam, the quantity of which is controlled by the spindle H, in the steam nozzle; the induced current of the air is formed in a series of nozzles of increasing area. The purpose of these nozzles is to regulate the admission and proper mixture of the inducing and induced currents in such proportions as not to lose power by sudden shocks. The quan-

tity of air to be admitted is regulated by a steam valve, H, and is always under the control of the fireman, and may be adjusted as circumstances require.

Figure 111 is a section at C, showing the compartment for heated gas over the top of the boiler. The line of the pendants, already described, is shown by the two lines, one on either side, and just below the water line of the boiler.

Figure 112 shows a section at the rear end of the boiler, and marked D, in figure 107. The arch is built down upon the boiler at this point, to prevent any such thing as a current of heated

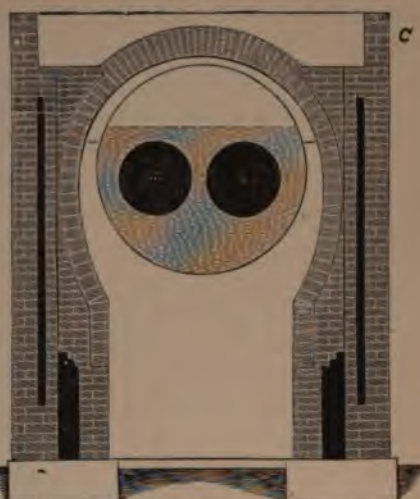


FIGURE 111.

gases over the top of the boiler; they are thus carried down below the water line, and below the bottom line of pendants already referred to.



FIGURE 112.

The area of openings at the sides and above the rear bridge wall are proportioned to the area of openings in the flues or tubes; practically, these side openings are made about one-third greater than the combined areas of the tubes or flues.

Figure 113 shows the method of utilizing the waste heat escaping up the chimney. The pipe supplying air above the

fire starts at the base of the chimney and ascends to near the top, thence downward and from the bottom to the jet blower, where it is forced into the cast iron box between the grates, as shown in figure 109.

The furnace doors, as usually fitted to this furnace, are shown in elevation in figure 114. Unlike the ordinary fire door, it is hinged at the top instead of the side. The door is slightly more than counterbalanced by means of two side weights, shown in the engraving. This weight has a segment of a gear cast inside, as shown in figure 115, into which a similar toothed segment, fitted to the door, is geared, and thus the movements of the door and weight are controlled by each other.

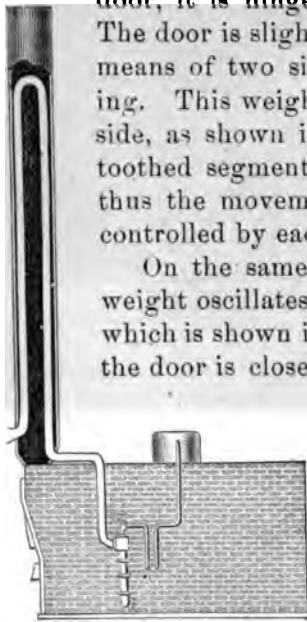


FIGURE 113.

On the same central shaft, around which the weight oscillates, is also secured a deflecting plate, which is shown in both figures 115 and 116. When the door is closed, as shown in figure 115, the deflecting plate is entirely within the housing. A butterfly register is attached to the door, through which a greater or less quantity of air may be admitted, as it may appear to be needed. When the deflecting plate is down, as shown in figure 115, the air passes underneath its lower edge, and is thus brought into close surface contact with the bed of burning fuel.

When the furnace door is opened in order to supply fresh fuel, the deflecting plate is thrown out horizontally, as shown in figure 116; the object of this deflecting plate being to prevent the cold air from impinging directly against the bottom of the boiler, but to so direct its course that it shall mingle with the heated gases immediately

over the fire, passing off with them without any local cooling of the lower part of the boiler shell.

The grate used in this boiler setting is quite narrow, and, as will be seen in figure 117, one is placed on each side of the central wall in the furnace. It belongs to that class known as oscillating or rocking grates, and is provided on

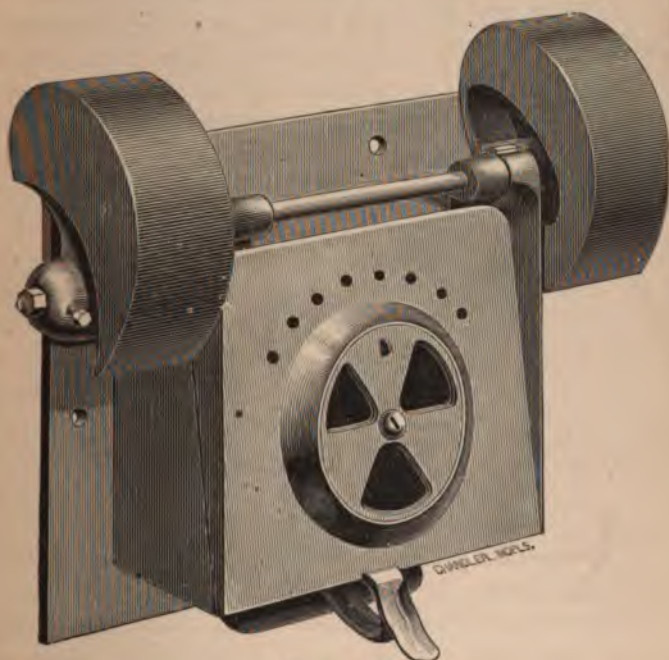


FIGURE 114.

its upper surface with oblique cutting edges and interlocking fingers, which also form parallel cutting edges.

The cross bar is corrugated in the direction of its length, and tapers from the top to its bottom; the fingers mentioned in the preceding paragraph are attached to it. These are "staggered," as shown in the engraving, so as to present a series of irregular orifices, which shall allow a

free and full supply of air to the fuel. These fingers are made semi-circular, and when the grate is being "rocked" or "shaken," the same distance is preserved as when in its

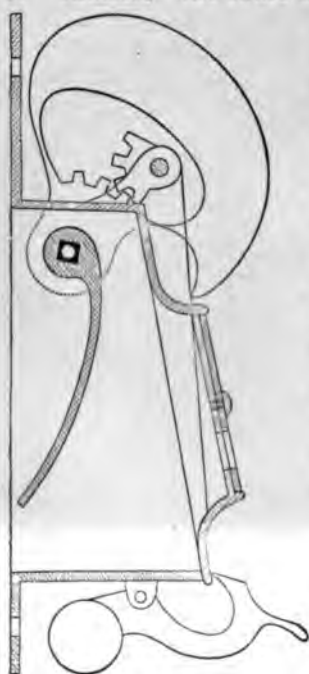


FIGURE 115.

normal condition, thus preventing the loss of any small fuel on the grate from falling through into the ash pit. Each grate bar has an arm projecting downward, as shown; these pass through suitable openings in a connecting bar, by which they may all be moved at once, which can be done without opening the furnace door. When the bars are shaken, the whole surface of the fuel is broken up, allowing at the same time complete access of air to the burning fuel.

Rocking grates are to be recommended where the character of the fuel will permit, because they always prevent in great measure, and oftentimes wholly, the clogging up of the free spaces between the bars. In burning any fuel likely to clinker, the spaces are liable to become filled up, and thereby interfere with the draft. By means of a rocking or oscillating grate, the clinkers are prevented from forming, by grinding or breaking them up as they form.

The following test of a boiler set with the Butman furnace at the flouring mill of G. W. Cunningham, Tiffin, Ohio, is by Isaac V. Holmes, M.E., who reports as follows:

This boiler was set with the Butman furnace and started on the first of August, 1876. It has therefore been in constant use over a year. On the third of August, 1876, I made an examination and tes

me, a full report of which was forwarded you at that time. The showed an evaporation at pressure of atmosphere and tempera-

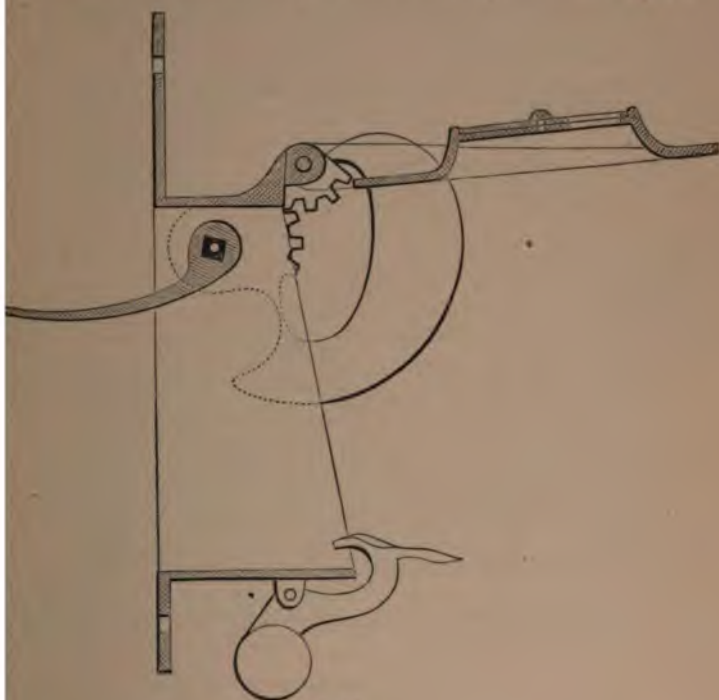


FIGURE 116.

f 212° of 11.33 pounds of water per one pound of Masillon lump
The object you had in view in making this second trial, as stated



FIGURE 117.

was to ascertain if the Butman furnace would retain its econ-
efficiency after being subjected to a year's work, and, also, how

A TREATISE ON STEAM BOILERS.

the various portions of the structure had withstood the wear and burning of the same.

Herewith is submitted a summary of results of the tests made on the twentieth instant (August, 1877):

DUTY.

Driving a four-run grist mill..... Clifton mill

COAL.

The kind used on this trial was.....Masillon nut

DURATION.

Continuous firing..... 7 hours

OBSERVATIONS.

Total amount water weighed to boiler	15,376 lbs.
Total amount coal weighed to furnace.....	1,233 lbs.
Total amount ash weighed dry.....	87 lbs.
Total amount combustible.....	1,136 lbs.
Average temperature feed water in tank.....	184°
Average temperature gases in uptake.....	340°
Average temperature air in pipe.....	132°
Average temperature air in fire room.....	97°
Average pressure steam in boiler.....	75°

PERFORMANCE.

Coal, per hour.....	176 lbs.
Combustible, per hour.....	162 lbs.
Water, per hour.....	2,196 lbs

RESULTS.

Pounds of water evaporated at 75 pounds pressure and temperature of 184° per one pound of coal.....	12.47
Pounds of water evaporated from pressure of atmosphere and temperature of 212° per one pound of coal.....	13.23
Equivalent evaporation from pressure of atmosphere and temperature of 212° per one pound of combustible.....	14.36

The evaporation of 13.23 pounds of water at pressure of atmosphere and temperature of 212° shows very conclusively that instead of losing its efficiency, it gives a higher rate of evaporation than at first although this is no doubt due to the familiarity of the fireman the furnace.

As regards the deterioration of the brick work or other portions of the structure will say, there was no perceptible wear to any portion of it, and I should not think that even the line of brick at the surface of the burning fuel would not require renewing for several years to come.

The boiler was 60 inches \times 18 feet, with fifty-six $3\frac{1}{2}$ -inch tubes; was fitted with two grates, as shown in figure 117, each $15\frac{1}{2}$ inches \times 4 feet. The mud drum was 20 inches \times 8 feet. Two things are noticeable in the above

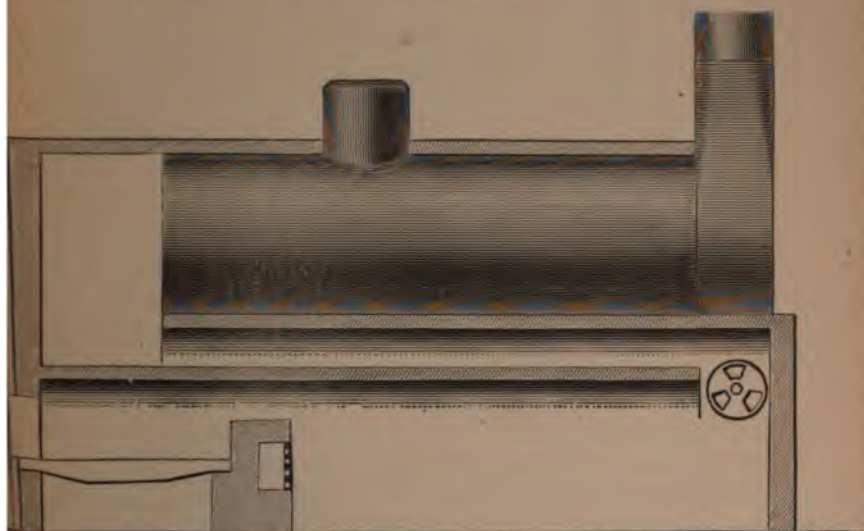


FIGURE 118.

test: the moderately high temperature of the feed water and the low temperature of the escaping gases. This is the highest rate of evaporation known to the writer, and if it were not for the ability and unusual care with which Mr. Holmes conducts his tests, the results might be discredited.

The Pierce furnace—The accompanying engravings show an improved design for boilers' furnaces, by Henry M. Pierce, LL.D., of Grand Rapids, Mich.

Figure 118 is a vertical longitudinal section, showing the boiler in position in the furnace. In this design the fire grate is wholly removed from the boiler and arched over, as may be more clearly seen in figure 119.

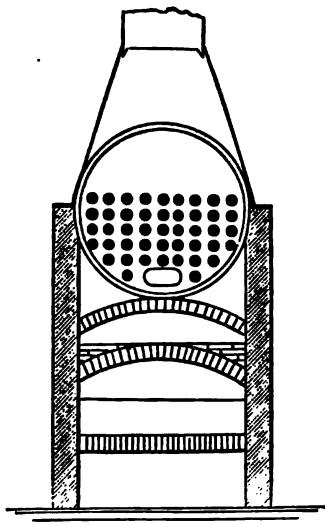


FIGURE 119.

The radiant heat of the fuel is not given out in this case so as to be absorbed by the boiler shell, but by the arch of fire brick overhead and along the flue. The advantages which such a form of construction offers toward effecting the complete combustion of hydrocarbon gases, when properly supplied with air, are too apparent to need any special explanation.

The furnace is fired in the usual manner, the products passing over a bridge wall, at a high temperature, into a roomy combustion chamber of equal if not still higher temperature. In this chamber, jets of heated air is admitted through the back of the bridge wall, through a perforated plate, as shown in figure 120. This supply of air in a chamber, at a temperature of over 1,000° Fahrenheit, has the effect to convert the volume of carbonic oxide into carbonic acid gas. The chamber being large, affords ample time for complete combustion; the passage of the gases through it is slow, because of its large area. The combustion being complete, the gases pass underneath the boiler, and from thence through the tubes to the chimney.

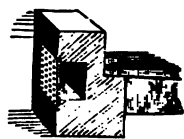


FIGURE 120.

A furnace, constructed after Dr. Pierce's designs, was on exhibition during the Exposition for the year 1879, at

burg, Pa., and is, in its details of construction, to be referred to the one described, when viewed from the standpoint.

Figure 121 is a full cross section showing the furnace and combustion cham-

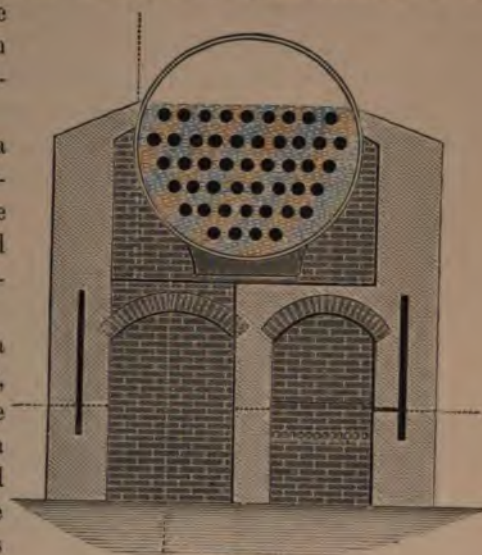


FIGURE 121.

Figure 122 is a plan view of the setting, showing the grate and combustion chamber back and side of the

The fuel is placed upon the

and, as in the setting first described, in a highly heated chamber, say 2,500° Fahrenheit. Jets of air are

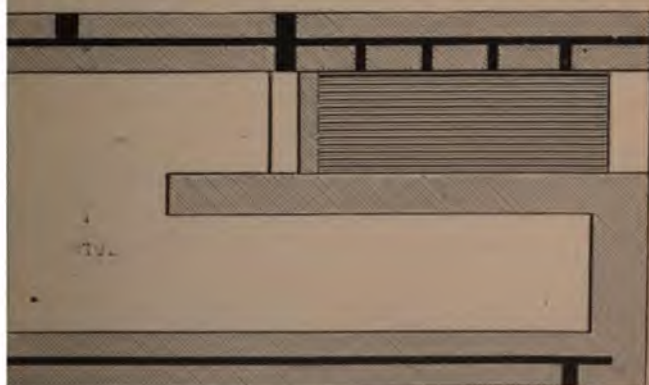


FIGURE 122.

ed along the sides of the grate, as shown in the

engraving. The walls are hollow, as shown by the black lines in the plan and elevations, and which serve to heat the air before its admission to the combustion chamber.

This furnace attracted a great deal of attention during the exposition. It was fired with Pittsburg coal, which was completely burned, and without the escape of any smoke. Suitable openings were made in the combustion chamber, which showed that the visible products were

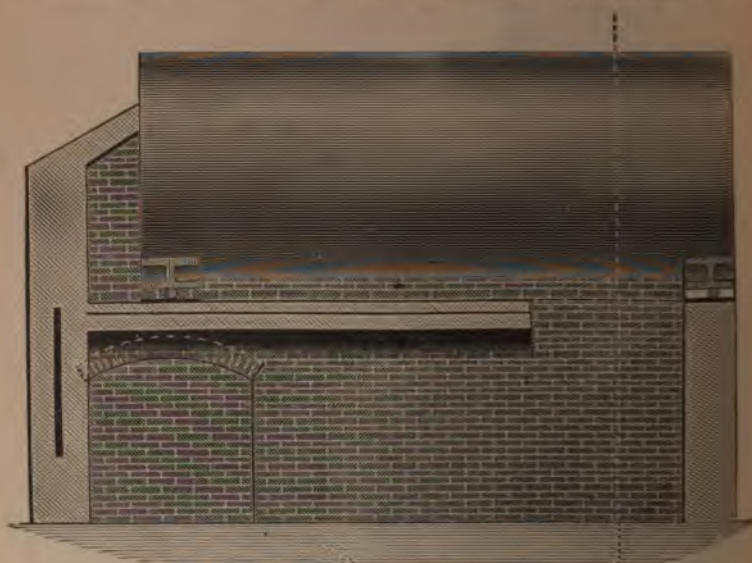


FIGURE 123.

destroyed immediately after they left the grate. Figure 123 shows a vertical longitudinal section, with the arched opening between the two combustion chambers.

CHAPTER XIII.

FEED APPARATUS.

Power Pumps—Strainers—Removing Sand from Feed Water—Water Chargers—Steam Jet—Steam Pumps—Dayton Cam Pump—The Cope & Maxwell Pump—Dean Brothers' Pump—The Knowles Pump—Auxiliary Pumps—Seller's Injector—Hancock's Inspirator—Schutte & Goehring's Injector—Pratt's Automatic Boiler Feeder—Snowden's Feed Pipe—Moore's Boiler Feeder.

Boilers are usually supplied with water by means of a pump or injector. Pumps may be divided into two classes; power pumps, or those driven by a belt, and steam pumps, or that class in which there is combined a steam cylinder and a pump. So long as the machinery is in motion, a power pump may be operated at a lower cost than a steam pump; the latter, however, may be operated at any time when steam is on, and is, on the whole, to be preferred even at its greater first cost and subsequent outlay for operating.

Whatever device may be selected for feeding boilers, it should be arranged in matters of detail so as to permit a constant feed into the boiler which shall exactly equal the evaporation; but this should not be the limit to its capacity.

In selecting a pump, allow one cubic foot of water per hour for each horse power of the boiler; the smallest size for the pump should be not less than twice that capacity when running at ordinary speed, and four times the

capacity may often be found to be a useful reserve in case of leaky valves, pipes, etc., which are not only liable to occur, but at a time when it may not be convenient to take the pump apart for repairs.

When a power pump is used, a combined lift and force

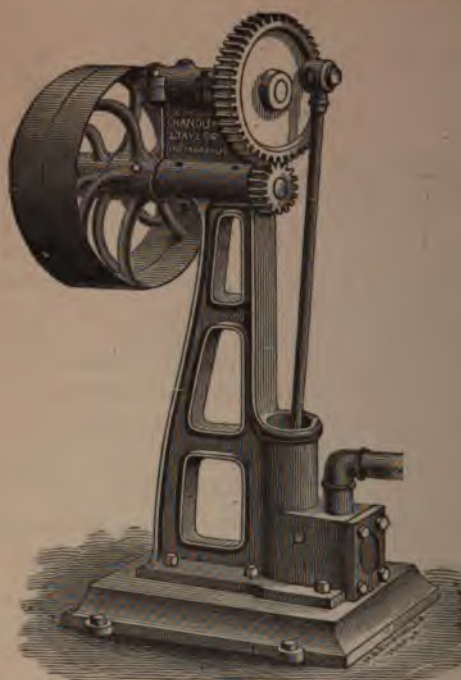


FIGURE 124.

pump is recommended; and, in pumping from a well, the delivery should be into a tank of sufficient size to supply the boiler for at least half a day. This will, in all ordinary cases, allow ample time for any small repairs that may be needed to the lifting or well pump. The force pump may draw the water from the tank and supply the boilers continuously. This arrangement of pumps and tank is

not always practicable, especially for very large powers, but whenever it can it ought to be done.

The engraving, figure 124, shows a very neat and compact single acting lift or well pump, by Chandler & Taylor, Indianapolis, Ind. It is fitted with leather valves, which are conveniently accessible. The piston is packed with hemp or jute packing. The counter shaft is fitted with tight and loose pulleys, and is thus self contained.

A boiler feed pump by the same firm is shown in figure 125. It is similar in design to the well pump, differing only in the plunger and valves. The connecting rod pin is near the middle of the plunger, and being always within the bearings of the pump barrel and gland, the plunger needs no other guides. The valves are of metal and suitable for pumping hot water. These may both be mounted on the same base and driven by the same belt.

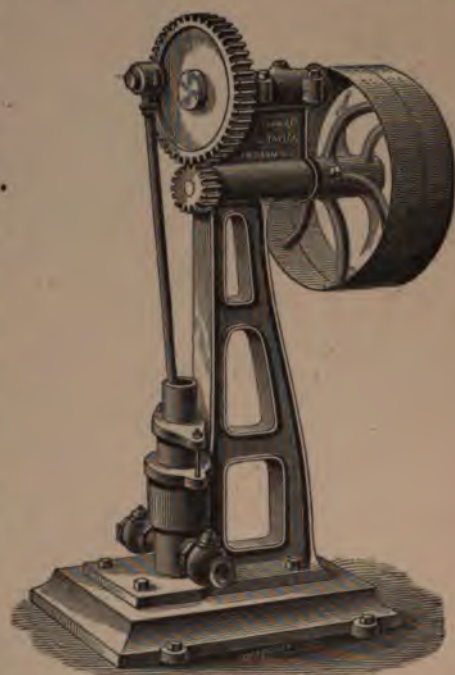


FIGURE 125.



FIGURE 126.



Pumps should be fitted with strainers and foot valves; one similar to figure 126 will be found quite reliable. It is intended to screw on the lower end of the pipe and should be placed near the bottom of the well. If a driven well is used there is always likely to be more or less trouble with sand in the water for some time after, in which case a device similar to figure 127, by W. and B.

Douglas, Middletown, Conn., may be attached to the feed

pipe and collect a large portion of the sand in the lower end of the chamber, from which it may be withdrawn by the removal of the plug shown in the engraving.



FIGURE 127.

spheric lift of the water. It is so simple as to need no special explanation. The quantity of water delivered is regulated by the steam valve, which may be located at any convenient place in the engine or fire room.

Steam pumps—Notwithstanding the lower cost at which power pumps may be operated, it is still, all things considered, in the interest of true economy to use a steam pump instead. The requirements of a steam boiler feeder are,

That it shall have no dead centers.

That it shall be simple in construction and durable in service.

Steam jets are often used for supplying a tank with water either from a well or stream, within a reasonable distance. A very simple and convenient device for raising water is shown in figure 128, made by Moore & Kerrick, Indianapolis, Ind. If the well is not deep, it may be placed near or above the ground, but may be carried any distance down the well to keep it within the atmos-



FIGURE 128.

That the working parts shall be readily accessible.

That it will not stop while there is sufficient steam to drive it, and if at rest it shall start at any portion of the stroke. The water valve chambers must be so constructed



FIGURE 129.

that by simply removing a cover the valves may be quickly got at for cleaning or repairs.

That it shall pump hot or cold water equally well.

Dayton cam pump—This pump, shown in elevation in figure 129, and in section in figure 130, is by Smith, Vaile & Co., Dayton, Ohio.

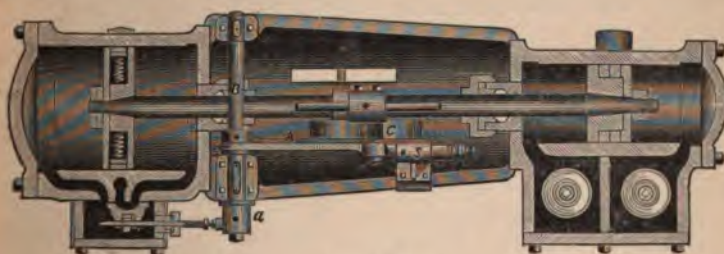


FIGURE 130.

By reference to the horizontal sectional view, it will be seen that it is a direct and double acting steam piston pump, having a plain slide valve, similar to the ordinary D valve of an engine. This valve is moved by two levers, A a, on a shaft B, being placed at right angles and form-

ing a bell lever. Motion is imparted to these levers by a cam C, bolted to the piston rod and working with it, a pin on the lever A working in a groove of the cam C; also, a fixed support or pocket, S, which holds a sliding V shaped plunger, P, and a spiral steel spring. The operation of the valve movement is as follows: The cam, C, near the termination of the stroke of the pump piston, brings the V shaped or pointed lever, A, in contact with the V shaped



FIGURE 131.

plunger, P, forcing it back in the pocket, S, and compressing the spiral spring contained in the pocket. The movement of the piston continues until the points have passed, when the forcible reaction of the spiral spring, and the pressure of the inclined faces of the V shaped points serve to move the lever, A, and, through it and the small lever, a, to throw the steam valve, V, sufficiently to partially open the steam port for the return stroke. The same operation is performed on the return stroke at its termination, only the lever, A, is thrown in the opposite direction. The arrangement of the water valves is extremely simple. The pump, being double acting, there are two suction and two

discharge valves, all contained in one water box on the side of the water cylinder. By reference to the sectional view of water box, a clear idea is obtained of the arrangement

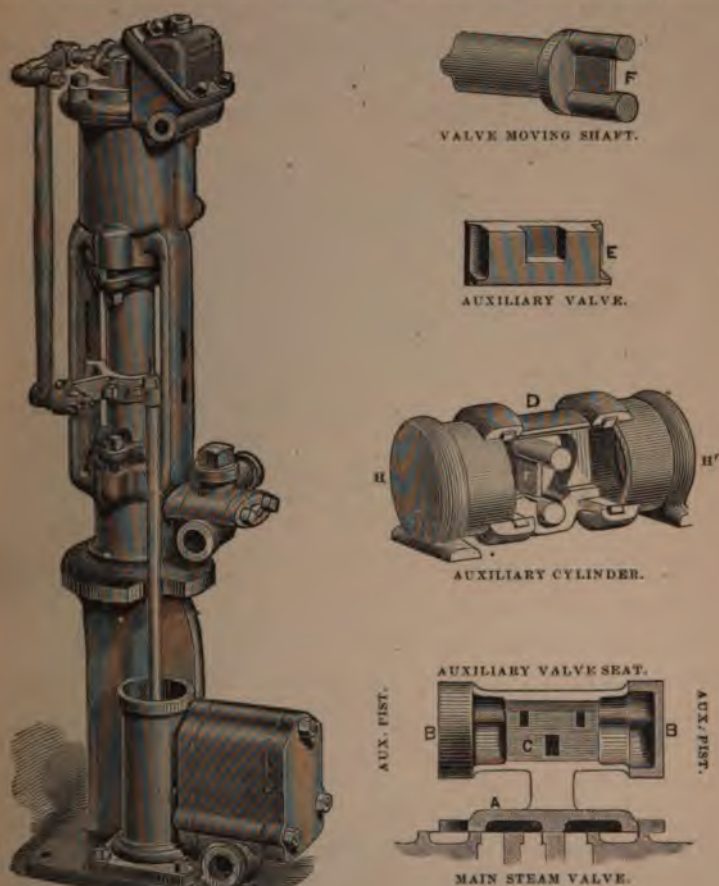


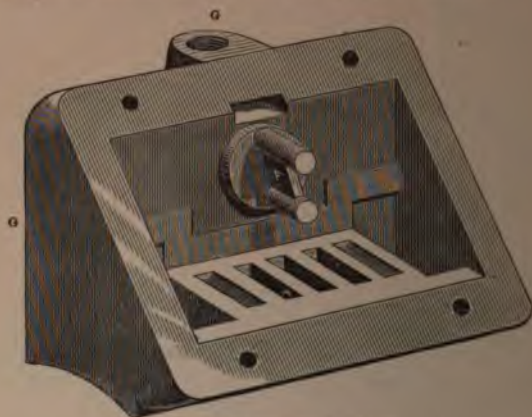
FIGURE 132.

of the valves, valve seats, stems, springs and plugs, and the manner of putting them in.

This pump possesses, what all pumps should, and that is, large steam and water passages. By an inspection of the

details of its moving mechanism, it will be seen that it can never make a short stroke; each stroke must be completed before the steam valve will open, to cause it to make a stroke in the opposite direction.

Figure 131 is a pump fitted with two cylinders, one for hot and the other for cold water. This is a step in the right direction, and can not fail of appreciation.



STEAM CHEST AND VALVE SHAFT.

The Cope & Maxwell pump made at Hamilton, Ohio, is shown in elevation in figure 132, and is, in this illustration, shown as a combined lift and force pump. The details of the valve movement will be understood by reference to the following description :

The steam chest, G, is cast in one piece with the steam cylinder head, and has neither bolt, nut, screw or joint of any kind, inside of it or about it, except its cap or cover. On removing the cap the entire valve movement can be lifted out, or any part of it removed and another substituted, ready for instant operation, without requiring to be fitted and without breaking or making a single joint, connection or attachment. There are no ports passing through gasket joints; no long crooked or small ports or holes to

get stopped up with dirt; no pockets to retain water and incur risk of damage from frost, and no point about it requiring adjustment.

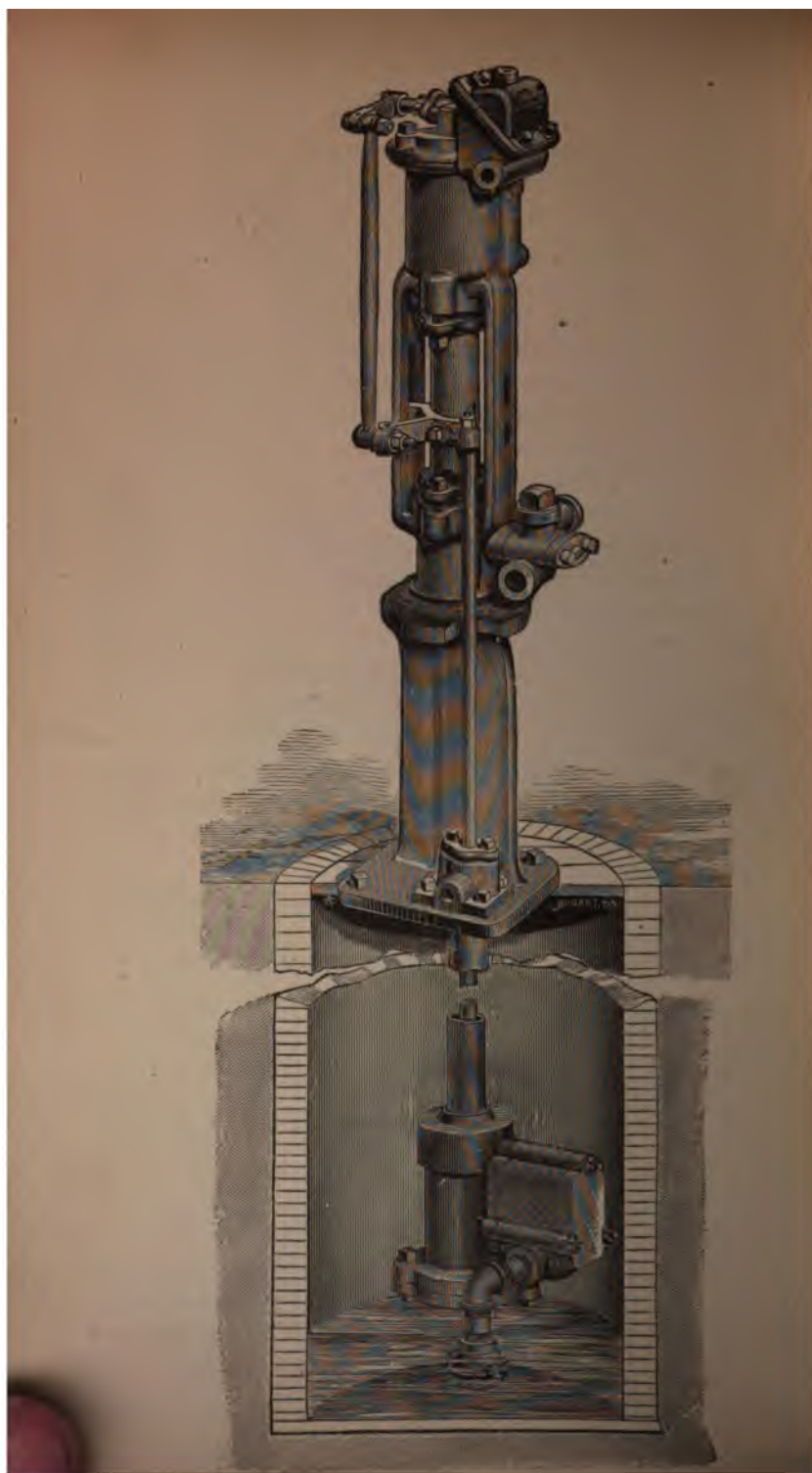
The main steam valve, A, is a flat slide valve, and is cast in one piece with the auxiliary pistons, B B, and the seat, C, of the auxiliary steam valve, E, as shown in engraving. It is moved continuously through the first half of its travels by the power of the main piston, and through the last half by the power of the auxiliary pistons, B B.

The auxiliary steam valve, B, is also a flat slide valve, and moved continuously by the power of the main piston.

The auxiliary steam cylinders, H H', are composed of two plain hoods or caps, each locking in to a central connecting piece, D, which holds them in position. They are put together or taken apart without the use of tools. It simply requires to be set down in its place in the steam chest, without further attention, to keep it in place. Being located in the steam chest, it is constantly surrounded by live steam, securing the best possible steam jacket without special provision.

The valve moving shaft, F, is a plain shaft extending through the back wall of the steam chest, connected on the outside to the main piston rod by means of lever and connecting rod, and terminating on the inside in a collar provided with two lugs, the lower one locking into the central or connecting piece of the auxiliary steam cylinders, H H', so they shall move together, and the upper, locking into a recess in the back of auxiliary steam valve so as to give the desired motion to it.

Operation—The reciprocating motion of the main piston communicates a rocking motion to the valve moving shaft, F, which, by means of its connection with the auxiliary steam cylinder, moves it back and forth. The main steam



valve, A, being cast in one piece with the pistons of the auxiliary cylinder, is moved with the cylinder, and it is so arranged that the main piston in making its full stroke causes the main steam valve, A, to move from its end to its mid position, cutting off both steam supply and exhaust in time to arrest the motion of the piston at the desired point, thus giving almost absolute uniformity to the length of strokes and furnishing it a very superior cushion.

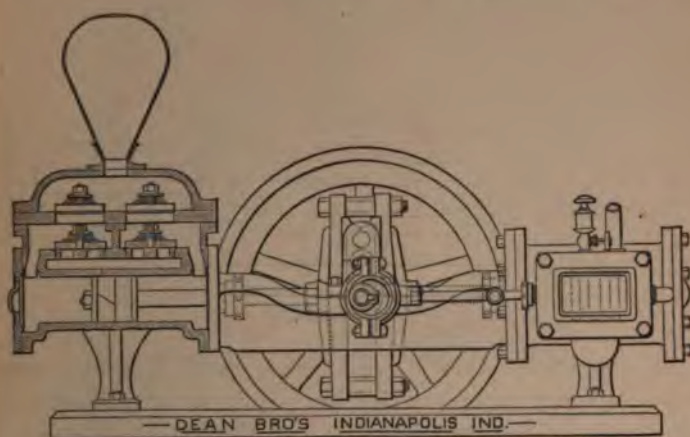


FIGURE 134.

Just before the main steam valve reaches its mid position, the auxiliary steam valve, E, moved by means of its connection with the valve moving shaft, F, reaches the proper position for giving steam to the auxiliary cylinder and motion to its piston. The main steam valve being one piece with this piston is thus carried from its mid position to the end of its travel, reversing the steam and its exhaust ports and the motion of the main piston.

Figure 133 shows the pump, as arranged for deep well pumping. The lower or lifting pump may be at any depth below the surface of the ground. The connection between

the lower chamber and the base of the pump is ordinary iron pipe, the lifting rod passing up through the center, as shown.

Dean Brothers' pump—This pump is shown in elevation in figure 134, in which a vertical longitudinal section of the water cylinder is also shown, with the valves in place. Figure 135 is a plan of the pump, showing the steam valve and ports, and the opening at the side of the water cylinder for the water supply.

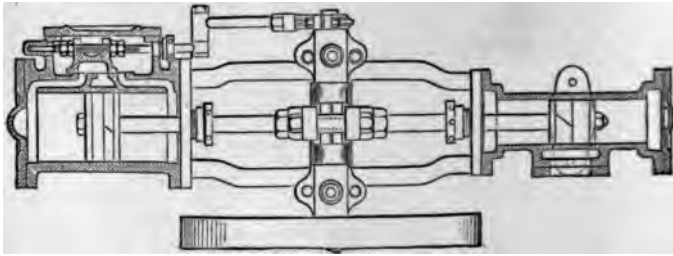


FIGURE 135.

It is a simple slide valve engine, combined, in a novel and compact manner, with the best form of a double acting pump. Care has been taken that the parts can be readily examined or removed, and all parts subject to wear have means of adjustment. It has but one steam valve. This is a flat slide valve, which embodies the most favorable conditions for tightness even after the wear consequent upon a long use. It is provided with a fly wheel, which causes it to run without concussion or jar, turns the centers softly and allows the water valves to seat quietly. The stroke is always the same. This wears the cylinders perfectly true, and discharges the full amount of water against the heaviest pressure.

The Knowles pump—This pump is shown in vertical longitudinal section in figure 136. Mr. L. J. Knowles,

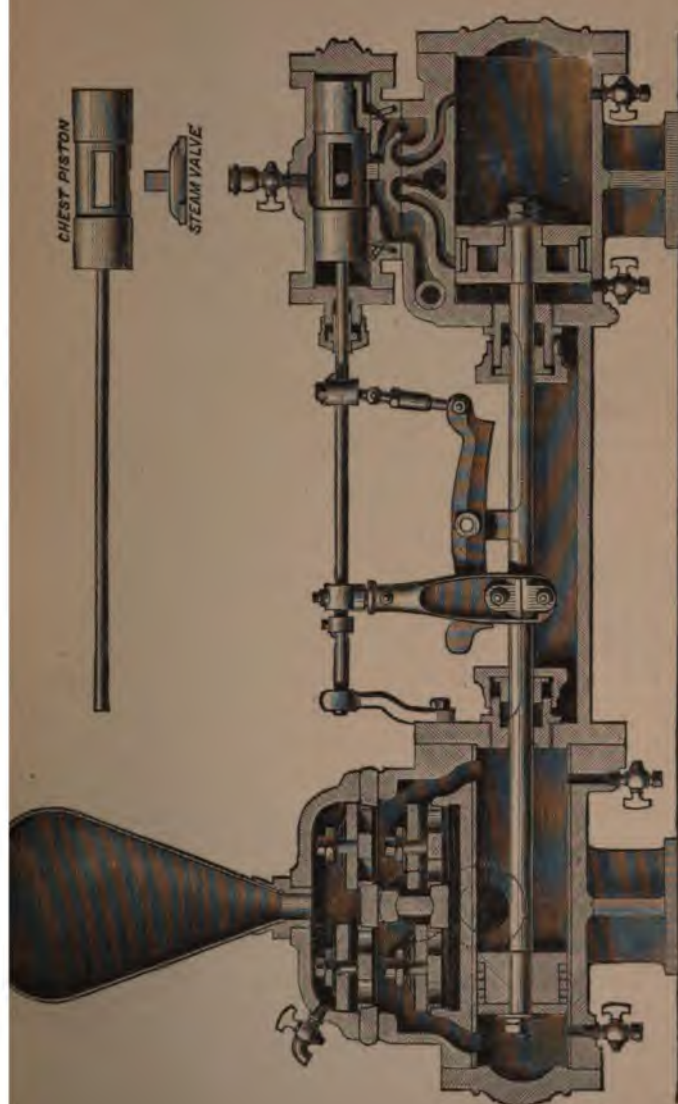


FIGURE 136.

Warren, Mass., was probably the first to introduce the direct acting, positive motion steam pump in this country. This pump has had a very large sale, and has proven a great success. The steam valve is a common flat slide valve, actuated by means of the valve driving piston, both of



FIGURE 137.

which are shown in detail in the engraving. The steam valve of the pump being an ordinary flat slide valve, does not have a rotary motion, but simply a horizontal motion, the same as any slide valve.

A flat valve embodies the most favorable conditions for securing tightness in the process of manufacture and retaining it in constant service. The slight rotary motion imparted to the valve driving piston, by the rocker arm, simply puts it in a position to be driven horizontally by the steam, in which motion

it carries the slide valve with it, both being directly connected together.

The driving piston is entirely independent of the exhaust steam for cushioning, thereby working with the same certainty and exactness when exhausting into vacuum (working condensing) as when exhausting into the atmosphere. It will always start at any point of the stroke, and recent improvements applied to the pump insure entire freedom from jar or pounding under varying conditions of pressure.

Auxiliary pumps—In every large manufactory, or in any case where the quantity of water required is too great to

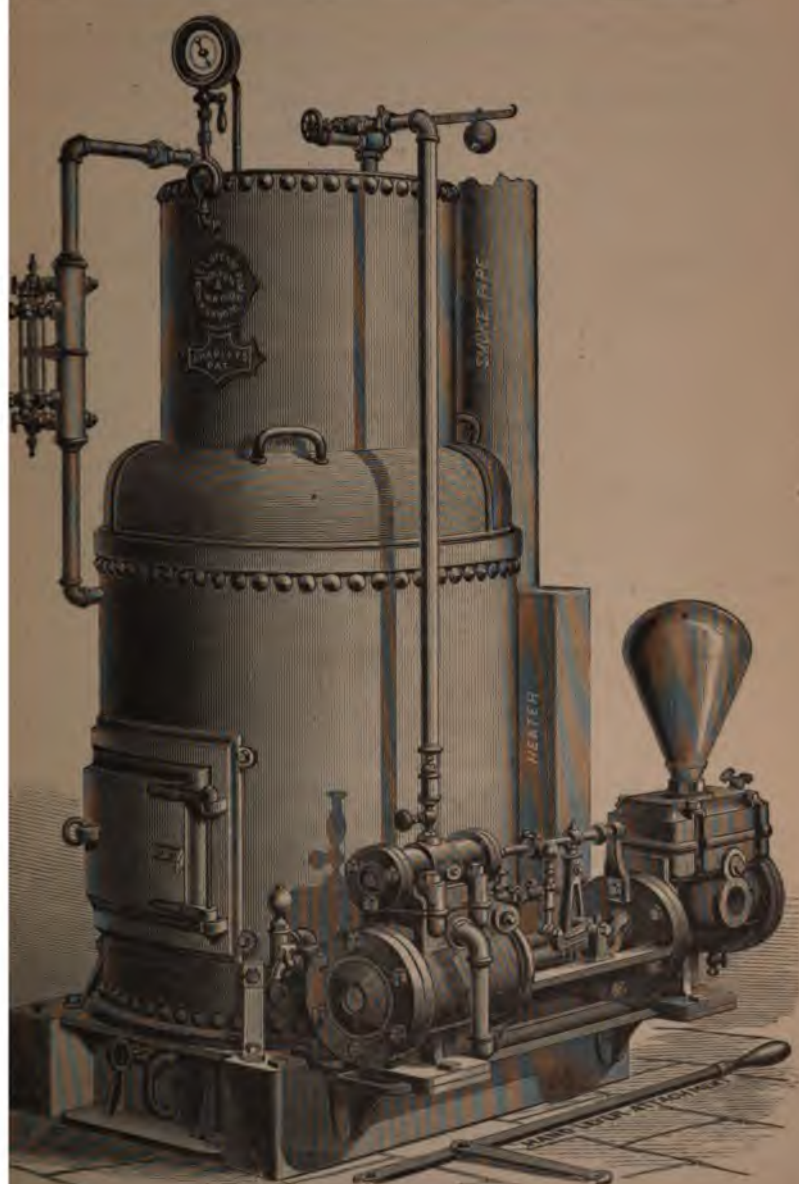


FIGURE 138.

have storage in suitable tanks, there should be an independent source of water supply for use at such times as the steam may not be on the main boilers. This will be found useful in washing out the main boilers during the process of cleaning. It may also serve a useful purpose as a fire engine, by starting a fire in the boilers about quitting time and place it in the care of the watchman during the night, and thus be ready for service at any moment. Figure 138 shows such a boiler and pump as made by the Knowles Steam Pump Works.

Should there be a difficulty in starting the pump on account of any defect in the suction pipe, a "charger," as shown in figure 137, may be employed. This should be of sufficient size to charge the water cylinder and fill the ports at least twice, after which there will be no trouble.

Injectors—This very ingenious and useful device for supplying boilers with water was invented by M. Giffard, of France. It was an innovation on old methods, and attracted the attention of engineers everywhere. Among the first to appreciate the value of this invention was the firm of William Sellers & Co., Philadelphia, Pa., who investigated its action, satisfied themselves as to its entire practicability, and at once received the right to manufacture. It was a fortunate circumstance, indeed, that this instrument, almost unknown and wholly untried in this country, had as its sponsor a firm whose reputation was already well established and who not only gave it their fullest endorsement, but labored diligently to improve it. The earlier instruments were in many respects faulty in their practical workings, but by successive changes and improvements, added year by year, the old injector has almost entirely lost its identity in the new. The principle, however, remains the same.

The Seller's injector is shown in elevation in figure 139, and represents the latest improved form. It is known as the "*Self-Adjusting 1876 Injector*," and will be best explained by reference to figure 140, which is a sectional view of the



FIGURE 139.

same instrument. It will be observed that it is self contained; that is, there is contained within the instrument itself the necessary steam and check valves required in its ordinary service.

The injector is operated by a single movement of the lever H, and its action may be traced through the instrument as follows: The steam, water, and boiler connections are indicated in the sectional view, and need no further description. By the movement of the lever H, the cross-head I slides on the guide-rod J, and thus communicates motion to the rod B, which passes through the stuffing box into the interior. A valve W, is secured to the rod B, and

has its seat on the upper side of another valve, X. The receiving tube A, contains both of these valves, and the passage of steam through this tube is prevented or controlled by the valve X. By a close examination of the

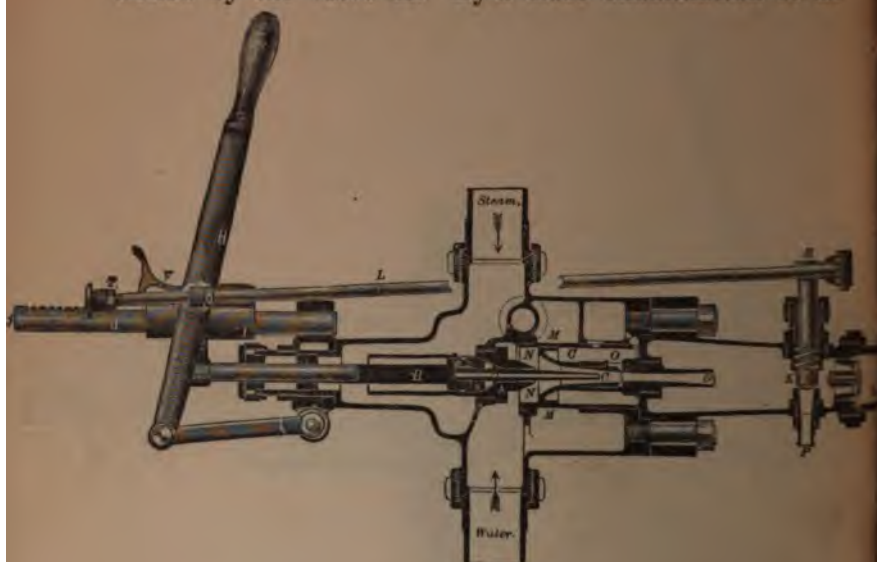


FIGURE 140.

engraving, there will be seen a hollow spindle beginning at W and terminating at C. This spindle passes through the valve X, and may be moved independently of it for a short distance, but by a further movement of the lever H, the valve X is raised from its seat by means of a step attached to the hollow spindle, formed by an enlargement of the spindle a short distance back of the valve X. Thus the first movement of the lever is to admit steam to the center of the spindle, by the unseating of the valve W and without disturbing the valve X. It will be understood that what has just been described belongs to the steam side of the injector.

The water enters, as indicated by the arrow, into the chamber surrounded by the cylinder marked M M. Inside of this cylinder is a piston N N, which terminates in a gradually contracting nozzle at a point just beyond C O. This piston is fitted to slide in the cylinder M M. By a slight movement of the handle H, a jet of steam will issue from the central hole in the spindle and a partial vacuum will be formed in N N; the water will be drawn into this tube, and forced through the delivery tube D. When sufficient water has passed through the instrument to flow "solid" out of the waste-orifice P, then the lever H may be drawn out to its full extent. By this single movement, the valve R is closed by means of the rod L, and the valve X opened, which will result in a continuous flow of water past the check valve into the boiler.

The rod L, shown in connection with the valve R and the lever H, is fitted with two stops, shown at T and Q. When the lever is thrown forward, as shown in the engraving, the valve R is raised from its seat by the screw shown at its lower extremity. When the lever is pulled back, so as to fully open the valve X, the valve R will be closed by the action of the stop T on the rod L. The lever H may now be moved at any point between the stops T and Q without affecting the waste valve; and by the movement of this lever the amount of water to be delivered is regulated.

The guide rod J is fitted with a number of teeth, as shown. A small click shown at V is hinged to the lever H, and is free to drop into the notches between the teeth in J. When the proper adjustment has been made by the lever H, for the water delivery, the click engages the space below and the injector will continue to deliver a quantity of water corresponding to the area of opening and pressure of steam.

The steam supply must be adjusted by the operator; the water supply is self regulating. If too much water is

delivered, some of it will escape through O into C, and, pressing on the piston N N, will move the combining tube away from the delivery tube, thus throttling the water supply; and if sufficient water is not admitted, a partial vacuum will be formed in C, and the unbalanced pressure on the upper side of the piston N N will move the combining tube toward the delivery tube, thus enlarging the orifice for the admission of water. From this it is evident that the injector, once started, will continue to work without further adjustment, delivering all its water to the boiler, the waste valve being kept shut. By placing the hand on the starting lever it is easy to tell whether or not the injector is working; and if desired, the waste-valve can be opened momentarily by pushing the rod L, a knob on the end being provided for the purpose.

These injectors are made in several sizes and numbered 2, 3, 4, etc. These are not arbitrary numbers but represent the diameter of the smallest part of the delivery-tube expressed in millimeters. Thus a No. 5 injector means that the tube through which the water is driven in passing through the delivery tube, is five millimeters in diameter. A No. 8 injector has a tube eight millimeters in diameter; and so for each of the sizes.

The non-adjustable injector with fixed nozzle, non-lifting, is shown in elevation in figure 141, and in section in figure 142. The latter figure, it will be observed, is reversed in the engraving, but will be none the less easily understood.

This injector differs from the one already described in being non-adjustable, and having no valve attached to it. The interior arrangement will be comprehended at a glance, after reading the description of the self adjusting instrument. This injector is best suited to localities where it may be operated under practically constant conditions—that is, where the steam pressure is nearly constant at all times.

TABLE LXXXIX.
TABLE OF MAXIMUM CAPACITIES OF PATENT SELF-ADJUSTING INJECTORS.
Wm. Sellers & Co.

NO. OF INJECTOR	SIZE OF PIPE FOR CONNEC- TIONS.	PRESSURE OF STEAM, IN POUNDS.														
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
		CUBIC FEET OF WATER DISCHARGED PER HOUR.														
2	1½ in.	8.3	9.	9.7	10.4	11.1	11.8	12.5	13.2	13.9	14.6	15.3	16.	16.7	17.4	18.1
3	¾ in.	19.27	21.04	22.81	24.58	26.35	28.12	29.89	31.66	33.43	35.2	36.97	38.75	40.53	42.31	44.09
4	1 in.	36.66	39.6	42.74	45.88	49.02	52.16	55.3	58.44	61.58	64.72	67.86	71.	74.14	77.28	80.43
5	1¼ in.	57.58	62.5	67.42	72.34	77.26	82.18	87.1	92.02	96.94	101.86	106.78	111.7	116.62	121.54	126.46
6	1½ in.	83.48	90.6	97.72	104.84	111.97	119.09	126.21	133.33	140.45	147.57	154.7	161.82	168.94	176.06	183.18
7	1½ in.	114.03	123.75	133.48	143.2	152.93	162.65	172.38	182.1	191.83	201.55	211.28	221.	230.73	240.46	250.19
8	2 in.	149.2	162.	174.8	187.6	200.4	213.2	226.	238.8	251.6	264.4	277.2	290.	302.8	315.6	328.4
9	2 in.	189.2	205.35	221.51	237.66	253.82	269.97	286.13	302.28	318.44	334.59	350.75	366.9	383.07	399.23	415.39
10	2 in.	233.84	253.8	273.76	293.72	313.68	333.64	353.61	373.57	393.53	413.49	433.45	453.41	473.37	493.33	513.29
12	2½ in.	337.2	366.	394.8	423.6	452.4	481.2	510.	538.8	567.6	596.4	625.2	654.	682.8	711.6	740.4
14	2½ in.	451.49	491.45	531.41	571.36	611.32	651.27	691.23	731.18	771.14	811.09	851.05	891.	930.97	970.93	1010.89
16	3 in.	600.22	651.6	702.98	754.16	805.44	856.72	908.	959.28	1010.56	1061.84	1113.12	1164.4	1215.68	1266.96	1318.24
18	3 in.	750.7	825.	899.93	974.91	1049.87	1124.81	1199.74	1274.67	1349.6	1424.53	1499.45	1574.38	1649.31	1724.24	1799.17
20	3½ in.	950.4	1050.	1150.16	1250.32	1350.48	1450.64	1550.8	1650.96	1751.12	1851.28	1951.44	2051.6	2151.76	2251.92	2352.08

SELLER'S INJECTOR.

It will be observed that it has neither steam nor check valves; these may be supplied by the ordinary steam



FIGURE 141.

fittings. Unlike the former injector, it is necessary to have a valve in the water pipe in order to regulate the supply, because the flow of water into this injector must be regulated with reference to the steam supply on account of the nozzles being fixed, and in consequence,

not self adjusting. If not supplied with the proper amount of water for the steam pressure under which it is working, it will leak at the waste valve when the water supply is too great.

To operate this injector, it is necessary to open the water supply valve first, the waste valve being open meanwhile, and when the water flows from the waste valve, partially open the steam valve until the jet is established, then quickly open it to

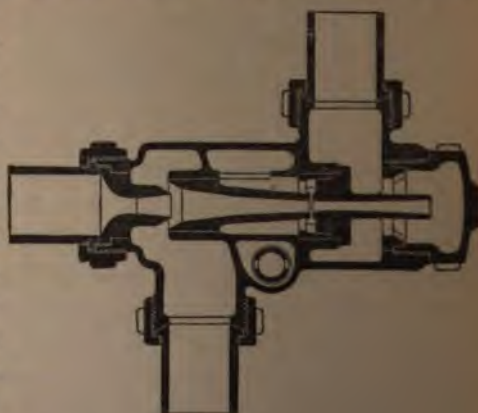


FIGURE 142.

its full extent. As the ordinary screw stop valve can not be easily or quickly handled, a special valve is made for

the purpose. The waste valve may be closed or not, but if the steam pressure is not constant it is best to leave it open.

This is not a lifting injector, and in consequence the water must be supplied to it so that it shall flow into the instrument, or be fed to it at any pressure, as for city mains. A modification of this instrument, with a lifting attachment, is shown in figure 143.



FIGURE 143.

The non-adjustable injector, with fixed nozzles, in connection with a lifting attachment, is shown in elevation in figure 143. This is a much more complete instrument than the one described in the preceding section, and in some respects is to be preferred to it. By referring to figure, 144 which shows the interior of this injector, there will be seen attached to the under side another and independent series of passages, arranged with a suitable nozzle to act as a steam jet or siphon.

By this arrangement water may be drawn from a lower level up and into the water chamber and through the

combining tube ready for the action of the main jet of the injector by the opening of the lower valve. When the jet is established the lower valve must be closed.

This injector, unlike the former, has a steam valve and check valve contained within it. In connecting this injector it must be provided with a water supply valve, for the reason that the nozzles are non-adjusting.

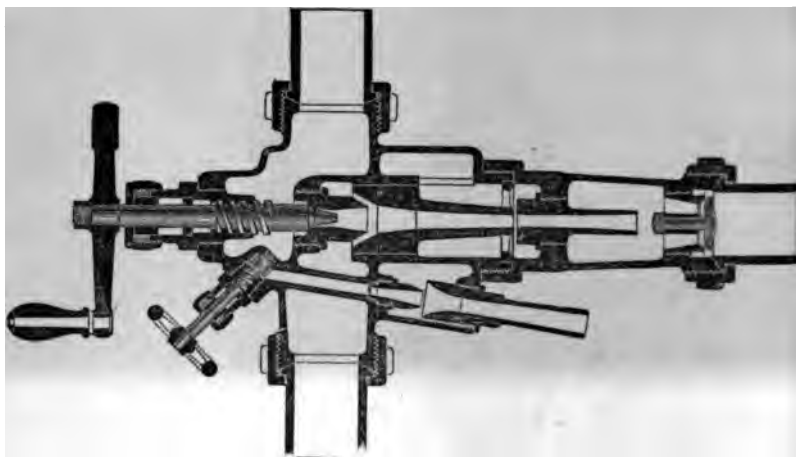


FIGURE 144.

Selection of an injector—Of the three instruments described the writer recommends the first as being best adapted for ordinary service.

To determine the size of injector needed for any particular case, a knowledge of the number of cubic feet of water required per hour will enable an injector to be selected, by referring to the table of capacities as given on page 357. The makers of this injector recommend that the one selected shall in no case be larger than is needed for the actual maximum requirement of the boiler. If too large an instrument be selected, the minimum delivery of water may be too great for the wants of the boiler, requir-

ing frequent stoppage to prevent flooding, which, apart from the trouble involved, is not so economical as a constant and regular feed equal to the drain on the boiler. For stationary boilers, where the work is nearly constant, the selecting of an injector is not attended with any special difficulty. Knowing the horse power required of the boiler, allow one cubic foot of water per hour per horse power for ordinary slide valve engines, and one half a cubic foot for the best automatic cut off engines, and the matter of selection by the aid of the table on page 357, becomes exceedingly simple.

The Hancock inspirator—This instrument is the invention of John T. Hancock, Suffolk, Mass., and differs from an injector in being a double instrument, one-half of which is a lifting and the other half a forcing apparatus; the lifter drawing the water from a well or tank and delivering it to the forcer, which then delivers it to the boiler, and at any steam pressure, without adjustment.

Two forms of inspirators are made; the one illustrated in figure 145 is a sectional view of the kind recommended for stationary boilers. The steam connection with the boiler is made at the end so marked in the engraving, and its course through the instrument is shown in the direction of the arrows. That side of the instrument at A is known as the lifting side, the other, B, C, D, as the forcing side. It will be observed that the steam current is divided in the upper chamber; a portion of the steam passing down through the vertical nozzle operates the steam lifting nozzle.

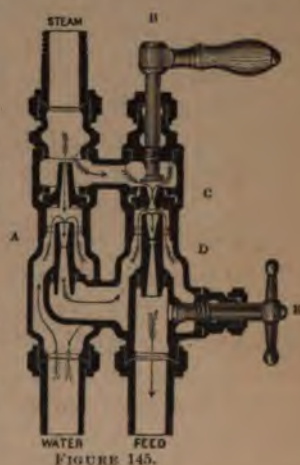


FIGURE 145.

zle at A, the water ascending around and passing down through the lower tube as shown, into a chamber, where it is delivered as also shown by the direction of the arrows into the nozzle opposite D, on the forcing side of the instrument. By raising the valve at B, steam is admitted through the nozzle at C, which acts as a forcing jet, compelling a flow of water through the force nozzle, D, and from thence to the boiler.

A valve is provided at E which determines the course the water is to take when delivered into the water chamber by the action of the lifting jet. This is to be opened when starting the instrument, and closed as soon as the action of the jet is established.

To regulate the delivery to the boiler it is only necessary to partially close the valve in the pipe leading from the inspirator to the well, and by also adjusting the steam valve by the handle at B. The usual steam, water and check valves are to be supplied.

The essential conditions to the successful operating of the inspirator, are,

1. A tight suction; the inspirator raises the water by causing a vacuum; of course, this can not be obtained without having the suction pipe and connections absolutely air tight.

2. Do not connect with other steam pipes, but take the steam direct by tapping the boiler; because, where steam pipes are already connected with the boiler, it is for some purpose, and they are not likely to be of sufficient capacity to supply the inspirator, and do the work for which they were originally designed. Again, the connection may be at a considerable distance from the boiler, so that the steam in the pipe is much reduced in pressure, and not so effective for the purpose as dry steam. Do not connect with a steam pipe, however

ge, that supplies the engine, if it can possibly be avoided, as the pressure will be so irregular and intermittent as to seriously interfere with the successful working of the inspirator. Tap the boiler where it will furnish the best steam, and if compelled to connect with a large steam pipe, tap it on the upper side, so as to avoid the drip caused by condensation in the large pipe, or the steam pipe will be little else than a drain to draw off the condensation in the large pipe.

Do not attempt to take water at a higher temperature than 120° Fahrenheit for a low lift, or higher than 100° Fahrenheit for a high lift. For a lift of 5 feet, about 10 pounds steam pressure is required; for 10 feet lift about 15 pounds steam; for 15 feet, 20 pounds; for 20 feet, 25 pounds; for 25 feet, 35 pounds.

The following are the sizes and capacities of inspirators offered to the trade:

TABLE LXXXX.

SIZE OF CONNECTIONS FOR THE HANCOCK INSPIRATOR.

NO. OF INSPIRATOR.	SUCTION AND FEED.	STEAM.	GALLONS PER HOUR, 60 LBS. PRESSURE.
7½	$\frac{3}{8}$	$\frac{3}{8}$	60
10	$\frac{1}{2}$	$\frac{3}{8}$	120
12½	$\frac{3}{4}$	$\frac{1}{2}$	220
15	$\frac{3}{4}$	$\frac{1}{2}$	300
20	1	$\frac{3}{4}$	540
25	1½	1	900
30	1½	1½	1,260
35	1½	1½	1,740
40	2	1½	2,230
45	2	1½	2,820
50	2½	2	3,480

When the consumption of fuel is known, the pounds consumed per hour will be the gallons evaporated. When the grate surface is known, and the draft is forced, multiply the grate surface in square feet by the draft, add 50 per cent for the pounds evaporated per hour.

A special form of inspirator is made for locomotive use, as shown in elevation in figure 146, and in section in figure 147.



FIGURE 146.

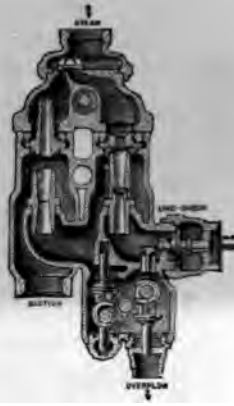


FIGURE 147.

The principle of action is the same for both designs; the locomotive inspirator has such an arrangement of parts and operated by suitable connections that, the starting, stopping or the regulating of the instrument while working, is controlled by the action of a single lever. It also contains the necessary steam, check and overflow valves. A slight movement of the starting lever admits steam to the lifting jet. When water issues from the overflow, a further movement of the starting lever closes one of the valves, thus turning the supply water through the force nozzle, admits steam to the forcing jet and closes waste valve, thus starting the instrument.

Schutte & Goehring's universal injector—This instrument is shown in sectional elevation in figure 148.

As will be observed, the instrument is a combination of two steam jet apparatus; the first one is proportioned for lifting and delivering the water under some pressure into the second one where its velocity is sufficiently augmented to overcome the counter pressure of the boiler. The

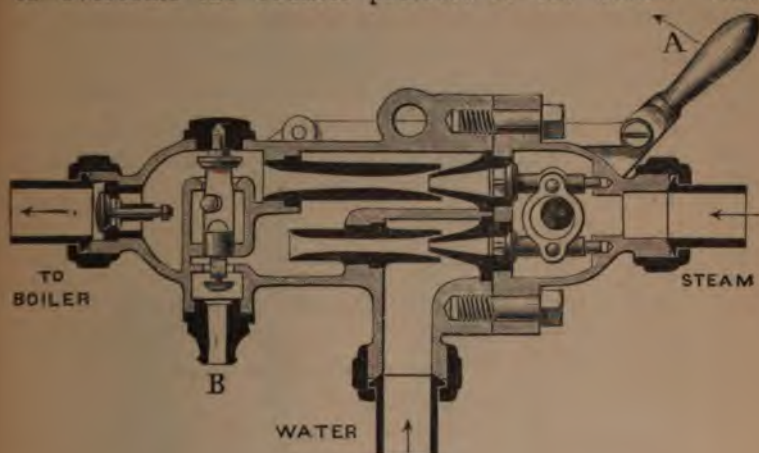


FIGURE 148.

explanation of the proper working of the injector, at the lowest as well as the highest steam pressures, without any adjustment of parts, is formed in the fact that the quantity of the water taken in by the first apparatus and delivered to the second one is directly in proportion to the pressure of the steam, so that the first one acts as a governor for the second one.

This combination of the two apparatus, and its self governing qualities without moving parts, makes the apparatus the least sensitive, a great desideratum on locomotives.

The limits of admissible temperature are, feed water 150° Fahrenheit delivered into the boiler, with 150 pounds steam at 250° Fahrenheit.

The injector may be fixed horizontal or vertical. There should be a steam stop valve and a main check valve on boiler. If water flows to the injector it is necessary to have a stop valve in the water pipe; it is also recommended in all cases to have such a valve for regulating the capacity of the injector.

If the injector has to draw the water, open the handle A, half way, or until the water is discharged through the starting cock, then open full. This stop need be of so short duration that a continuous moderately slow movement will accomplish the required result, so that the instructions for manipulation would read: To start, open with handle A. To stop, shut with handle A.

TABLE LXXXXI.
CAPACITIES OF SCHUTTE & GOEHRING'S INJECTOR.

SIZE, NO.	SIZE OF CON- NEC- TION.	PRESSURE OF STEAM, IN POUNDS.								
		15	30	45	60	80	100	120	140	160
		CUBIC FEET OF WATER PER HOUR, OR HORSE POWER OF BOILER.								
2	$\frac{1}{2}$	8	9	10	11	12	14	15	16	18
3	$\frac{3}{4}$	18	20	22	24	28	31	34	37	41
4	1	35	40	45	50	55	60	65	70	75
5	$1\frac{1}{4}$	52	58	66	73	80	87	94	103	110
6	$1\frac{1}{2}$	80	90	100	110	120	130	140	150	160
7	$1\frac{3}{4}$	104	122	140	158	176	194	212	230	248
8	$1\frac{1}{2}$	140	160	180	200	220	240	260	280	300
9	2	175	200	225	250	275	300	325	350	375
10	2	220	250	280	310	340	370	400	430	460
12	$2\frac{1}{2}$	310	360	410	460	510	560	610	660	710

A combined feed water heater and boiler feeder, as manufactured by the Steam Boiler Appliance Company, Hartford, Conn., is shown in figure 149, in general elevation, with the several attachments, all made to illustrate its mode of operation.

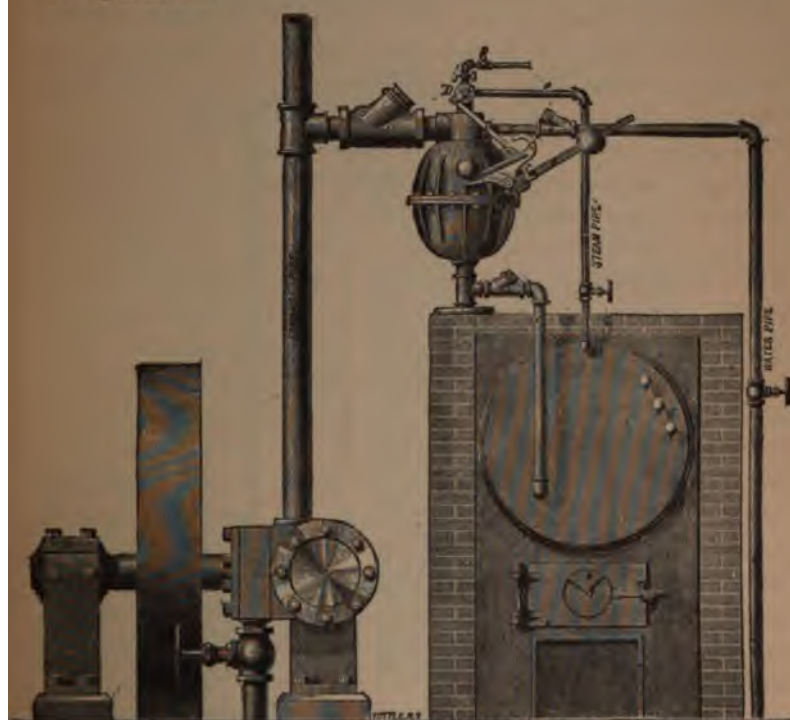


FIGURE 149.

A is the body of the heater and feeder, inside of which is a tight, hollow cast iron sphere, suspended on one end of a lever, the other end of which is fast to a spindle, running through a stuffing box to the outside, and carrying on its outer end lever B, with the weight which counterpoises half or more of the weight of the sphere inside the heater. C is a rocking lever, carrying a grooved weight,

which rolls to either end of lever C alternately as the heater is filled and emptied, the rolling weight moving at the same point every time, tripping the steam valve D open and shut. E is a connecting rod between valve D and rocking lever C. F is the feed pipe to boiler. H is a steam pipe from the boiler to valve D; this pipe must come direct from steam space of boilers. J is an air or vent cock. K is a check valve on air pipe, opening outward. L are check valves on exhaust, water inlet and outlet pipes.

In the cut the steam valve D is closed, and the water entering the heater causes a partial vacuum, so that all the exhaust steam that the water will absorb is drawn into it, heating the water to the highest temperature attainable by use of exhaust steam without back pressure on the engine. As the heater fills with water, the iron sphere or bucket inside is raised by it, and lever B goes down until it has elevated the inner end of rocking lever C sufficiently to cause the grooved weight to roll to the outer end, opening the steam valve D and allowing the boiler pressure to be thrown instantly on top of the water in the heater, and seating the check valves on water and exhaust pipes so that steam from the boiler can not pass into them; the water is now quickly discharged into the boilers by its own gravity, and as the water runs out of heater lever B goes up until the grooved weight rolls inward and closes the steam valve.

The cold water enters the heater in different ways, according to the amount of its pressure. Where it is heavy a positive valve is put on for it to run through; therefore it is necessary to know the amount of pressure in boilers, the amount of cold water pressure, size of engine (H. P.), size of exhaust pipe from engine, what portion of the steam made in boilers is used by the engine, size of feed pipes to boilers, and elevation the heater can be set above the boilers. As the capacity of the heater and feeder

depends very much upon the circumstances under which it is used, it is necessary to have all these particulars in order to adapt the apparatus to the work to be done.

By means of suitable connections this same apparatus may be used as an *automatic boiler feeder* and *return steam*



FIGURE 150.

trap, and may be used for supplying boilers with water from all sources where there is pressure enough to lift it above the boiler, such as hydrants or tanks, and also condensation from steam heating or drying pipes, drying cylinders, boiling pans, main steam pipes to engines, or wherever condensation occurs under pressure, whether above or below the boilers.

The apparatus with the connections is shown in elevation in figure 150. Similar letters of reference in this engraving refer to similar parts as described in figure 149.

The small valve shown on the trap, connected to steam valve D, is used where the water pressure is sufficient to run into the boiler against the pressure in it, if returning from high pressure circulations, etc., or if returning from low pressure dryers, slashers, etc., if the water pressure is above that used in them. The water going through this valve can come through a heater where an engine is used. The feeders should be set from two to six feet above the water line of boilers; the higher, the quicker the discharge.

Admission of feed water into the boiler—The usual practice is to supply boilers with the feed as far from the furnace as possible, and near the bottom of the boiler. It may be questioned whether this is the best thing to do. If the water entered the boiler at or near the boiling point it would make but little difference where the feed pipe made its connection, so long as the delivery was at a distance of several inches from the bottom of the shell, if it is an externally fired boiler.

As to the amount of injury done a boiler, a great deal will depend as to whether the feed water impinges against highly heated plates, and whether a good circulation is had in the boiler. The tendency of the cold water entering at the back of the boiler is to descend and traverse along the bottom of the shell toward the front end, that being the direction of the circulation of water. During this time there is a diffusion of heat, in which the feed is constantly receiving increments of heat from the surrounding and intermingled particles already more highly heated, and which are moving in the same direction. Just what distance the feed has to traverse in this current before it becomes harmless when it comes in contact with the

plates, the writer does not know, and he is not aware of any experimental data relating to it.

Boilers commence leaking water by the rivet holes becoming elongated by the strain produced by contraction, and they often break out and are required to be replaced by new sheets. This is not only troublesome to engineers, and expensive to owners, but it is a source of great danger also, as no doubt many disastrous explosions have occurred

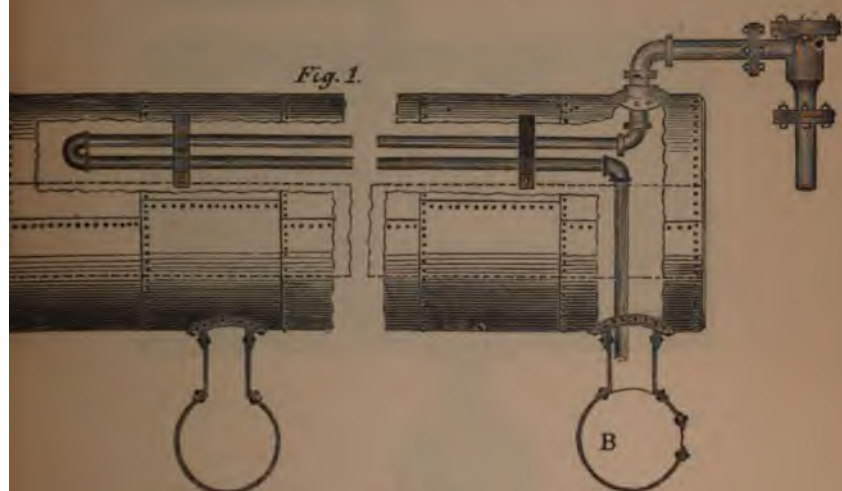


FIGURE 151.

from this cause. Figure 151 is a representation of a device for feeding boilers, by Thomas Snowden, Pittsburg, Pa.

The nature of the improvement consists in locating a feed water pipe within the boiler, having one end of the pipe communicating with the feed pump, by being attached to the check valve, C. The pipe is then carried through the shell of the boiler and connected with a horizontal pipe running along the boiler above the water line, to near the opposite end, after which it returns to the end at which it entered, and turning down to the stand pipe, dis-

charges into the water space of the same. The check valve may be if necessary, placed below, the supply pipe entering the boiler through the stand pipe and running up to the horizontal pipe. By this means the feed water is heated within the boiler, in its passage through the pipe, before it empties into the water space; thus the destructive consequences which result from introduc-

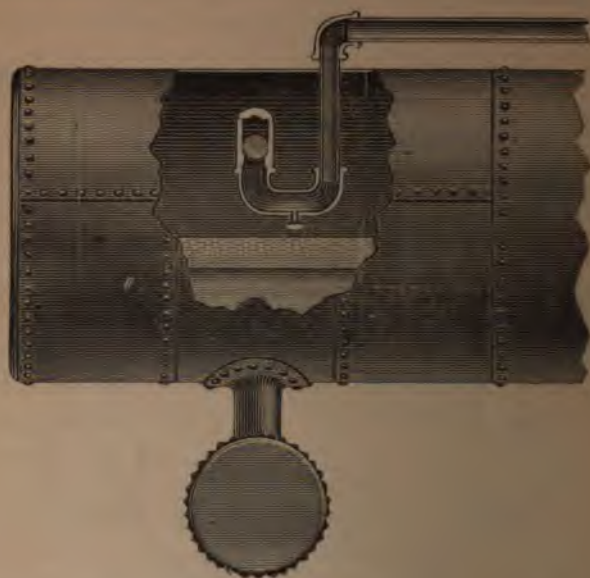


FIGURE 132.

ing water of a lower temperature than the boiler plate is prevented.

Moore's boiler feeder and cleaner is represented in figure 152, and is the invention of Mr. George W. Moore, Pittsburg, Pa. The object of introducing the feed into the steam room of the boiler is to impart to the water a high temperature before it comes in contact with the boiler plates.



The water is admitted through the shell of the boiler and discharges upwards through the check valve, as shown. The feed water, falling on the surface of the water in the boiler, mingles with it, and it is claimed with less injury to the shell than by any other method. It is equally applicable for hot or cold water and will work with any device used for forcing water into the boiler. It is claimed that the first effect of this heater is to detach or loosen the old scale in the boiler, and it has been found necessary to wash out and examine the boiler after applying the heater.

The boiler should not be run more than three weeks without washing out, and as the boiler becomes cleaner, the running time may be extended to one month, and when the boiler becomes clean and free from scale, all that will be necessary to keep it clean will be to blow out at the mud valve two or three times a day. By the observance of this rule, there will be no danger of burning a boiler, which would be the result if the loose scale was not removed.

CHAPTER XIV.

HEATERS AND ECONOMIZERS.

Gain by the use of Heaters—Coil Heaters—Stillwell's Lime Extractor and Heater—Green's Heater—Victor Heater—Kemp's Boiler Cleaner—Stead's "Circulating Generator"—Economizers—Babcock & Wilcox Economizers—Johns' Asbestos Covering—Chambers-Spence Covering.

The advantages to be gained by heating feed water to as high a temperature as possible before allowing it to enter the boiler, is so apparent that it need not be enlarged upon.

This gain, however, should be entirely that of reclaiming from the waste gases from the furnace or from the exhaust steam, heat which would otherwise be lost.

In order to illustrate this saving, let us suppose a boiler to be carrying steam at 60 pound pressure per square inch, as indicated by the gauge, the temperature of the feed water being at 60° Fahrenheit.

By referring to table LIX, on page 205, we find the total heat required to generate one pound of steam at 60 pounds pressure from water at 32° Fahrenheit to be 1175.2 heat units. This represents the quantity of heat abstracted from the furnace to generate one pound of steam at 60 pounds pressure, the feed being 32° Fahrenheit; if, however, the feed be 60°, as already suggested, then each pound of steam would abstract from the furnace 1147.2 heat units. If the temperature were 200°, then $200 - 32 = 168^\circ$, which, subtracted from 1175.2 = 1007.2 heat units, and in this manner for other temperatures.

TABLE LXXXXII.

PERCENTAGE OF SAVING OF FUEL BY HEATING FEED WATER.*

(Steam at Sixty Pounds).

FINAL TEMPERATURE.	INITIAL TEMPERATURE OF WATER.												
	32°	40°	50°	60°	70°	80°	90°	100°	120°	140°	160°	180°	200°
50°	2.39	1.71	0.86	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
80°	4.09	3.43	2.59	1.75	0.88	.....	.....	.....	.....	.....	.....	.....	.....
100°	5.79	5.14	4.32	3.49	2.64	1.78	0.90	.....	.....	.....	.....	.....	.....
120°	7.50	6.85	6.05	5.23	4.40	3.55	2.68	1.80	.....	.....	.....	.....	.....
140°	9.20	8.57	7.77	6.97	6.15	5.32	4.49	3.61	1.84	.....	.....	.....	.....
160°	10.90	10.28	9.50	8.72	7.91	7.09	6.26	5.42	3.67	1.87	.....	.....	.....
180°	12.60	12.00	11.23	10.46	9.68	8.87	8.06	7.23	5.52	3.75	1.91	.....	.....
200°	14.30	13.71	13.00	12.20	11.43	10.65	9.85	9.03	7.36	5.62	3.82	1.96	.....
220°	16.00	15.42	14.70	14.00	13.19	12.33	11.64	10.84	9.20	7.50	5.73	3.93	1.98
240°	17.79	17.13	16.42	15.69	14.96	14.20	13.43	12.65	11.05	9.37	7.64	5.90	3.97
260°	19.49	18.85	18.15	17.44	16.71	15.97	15.22	14.45	11.88	11.24	9.56	7.86	5.96
280°	21.16	20.56	19.87	19.18	18.47	17.75	17.01	16.26	14.72	13.02	11.46	9.73	7.94
300°	22.83	22.27	21.61	20.92	20.23	19.52	18.81	18.07	16.49	14.99	13.37	11.70	9.93

Coil heaters—The commonest form of a feed water heater is a large pipe, usually of cast iron, containing a number of smaller wrought iron pipes, which traverse the length of the interior several times, the feed water passing through the inside of the smaller pipes, and the exhaust steam from the engine filling the larger shell. In this manner a considerable saving is effected; the amount may be determined by the use of the above table. As no further use is usually made of the exhaust steam after leaving the engine, any heat which may be abstracted by the feed water in this way is nearly all clear gain.

* From "Steam," by Babcock & Wilcox, N. Y.

Stillwell's lime extracting heater and filter combined, as manufactured by the Stillwell & Bierce Manufacturing Company, Dayton, O.,

is shown in sectional elevation in figure 153. The details of its construction will be easily understood by reference to the following letters contained in the engraving, the several functions of the parts referred to being as given below :

A—Steam enters the heater, and is divided into two currents. B—Steam escapes from the heater. C—Cold water enters. F—Cock with which to regulate supply of cold water. H—Door of heater. J—Hot water leaves heater. L—Glass water gauge. a—Overflow cup suspended on the end of cold water pipe. b b b b—Removable shelves or depositing surfaces. c—Filtering

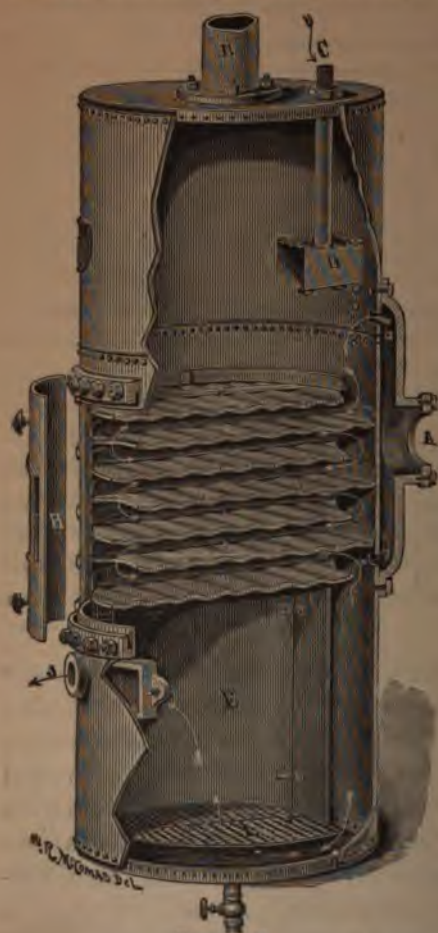


FIGURE 153.

chamber to be filled with any suitable filtering material. The feathered arrows indicate the course of the steam, and the plain arrows the course of the water.

Its operation is as follows: Connection is made at A with the escape pipe from the engine, where the steam is divided and enters the heater at two ports, one just above the upper shelf, the other opposite the lower shelf. The outlet pipe, B, for the escape from the heater of the uncondensed steam, is of the same size as the inlet pipe A. The escape steam from the heater may be carried to any desired point and applied to any further use, such as heating rooms, steaming lumber, etc. (These steam passages are of such ample size that it is impossible that the heater should create any back pressure upon the engine, but, on the contrary, the partial condensation of the escape steam tends to relieve an engine of back pressure). The cold water is brought from a tank by pipe C into the top of the heater, the supply being regulated by a suitable stop cock. Upon the end of this cold water pipe on the inside of the heater, and located just above and in front of the upper steam port, there is fastened a wedge shaped cup, called the overflow box. The water fills this cup and flows over its edges in a widely distended thin sheet, falling down through the incoming current of steam onto the upper shelf. The steam passing thus through a thin sheet of water, dashes it into fine spray, acting upon each separate particle, and imparts to the water sufficient heat to raise it to the boiling point, which sets free and precipitates the lime or other salts held in solution. The water now traverses a large area of heating and depositing surfaces, arranged in the form of removable shelves, having alternate openings. As the thin sheet of water passes over these shelves, all of which are very hot, and descends from shelf to shelf, it is met in its downward course and constantly acted upon by the ascending current of steam which enters the heater at the lower port. The action of this lower current of steam completes the separation and precipitation of the foreign particles which is begun when the water enters the heater.

It will be observed that the construction of the heater is such that not a drop of water can pass down through it without being thoroughly boiled. The lime, magnesia, sulphur, iron, silica, etc., which this process of boiling sets free from the water, are deposited in a crystallized state upon the entire series of shelves, the deposit always being heaviest upon the upper shelf and diminishing in quantity as it approaches the lower shelf. From the lower shelf the water, which has now parted with all that portion of its impurities which will crystallize, passes down behind the back of the filtering chamber into the mud well in the bottom of the heater, where the mud, sand, and uncrystallized particles of lime, etc., are deposited, and from whence they may be drawn off, through an opening for that purpose in the bottom of the heater, as often as may be necessary. The purification of the water is now completed by its passage from the mud well upward through the false bottom and the filtering chamber C to its final exit from the heater at J. The filtering chamber is tightly packed with hay, straw, or other suitable filtering material, which effectually retains all the light floating particles not previously arrested. By the process thus described, water that is heavily impregnated with lime, magnesia, sulphur, iron, silica, clay, mud, sand, etc., is robbed of much these scale producing substances, and supplied to the boiler nearly boiling hot and almost pure.

This system of filtering the water is one which effectually removes mud, sand and all other impurities which will not crystallize and adhere to the shelves. As will be seen by referring to the sectional engraving, the water, after making the circuit of the shelves, passes behind the water shed directly to the bottom of the heater, thence up through the perforated plate, upon which the filtering material rests, and on up through the filtering material to the discharge pipe J. The great superiority of an upward

filter over a downward or side filter, all who have had any experience in this direction will readily admit. All the particles of mud and sand, instead of being dragged by the current of water through the filter, as in downward or side filters, settle readily to the bottom of the heater, from whence they are drawn off or blown out through a waste pipe for that purpose. In some cases, when the water used is exceedingly muddy, the makers attach to the bottom of the heater a mud well and outside upward filters, with which arrangement they almost perfectly purify Missouri river water, which is well known as the muddiest water in the country. The writer has furnished a number of these combined heaters and lime extracters, in contracts which came under his superintendence, and from the very favorable workings of the apparatus under many conditions, does not hesitate to recommend it as being, in the main, all that the manufacturers claim for it.

TABLE LXXXXIII.

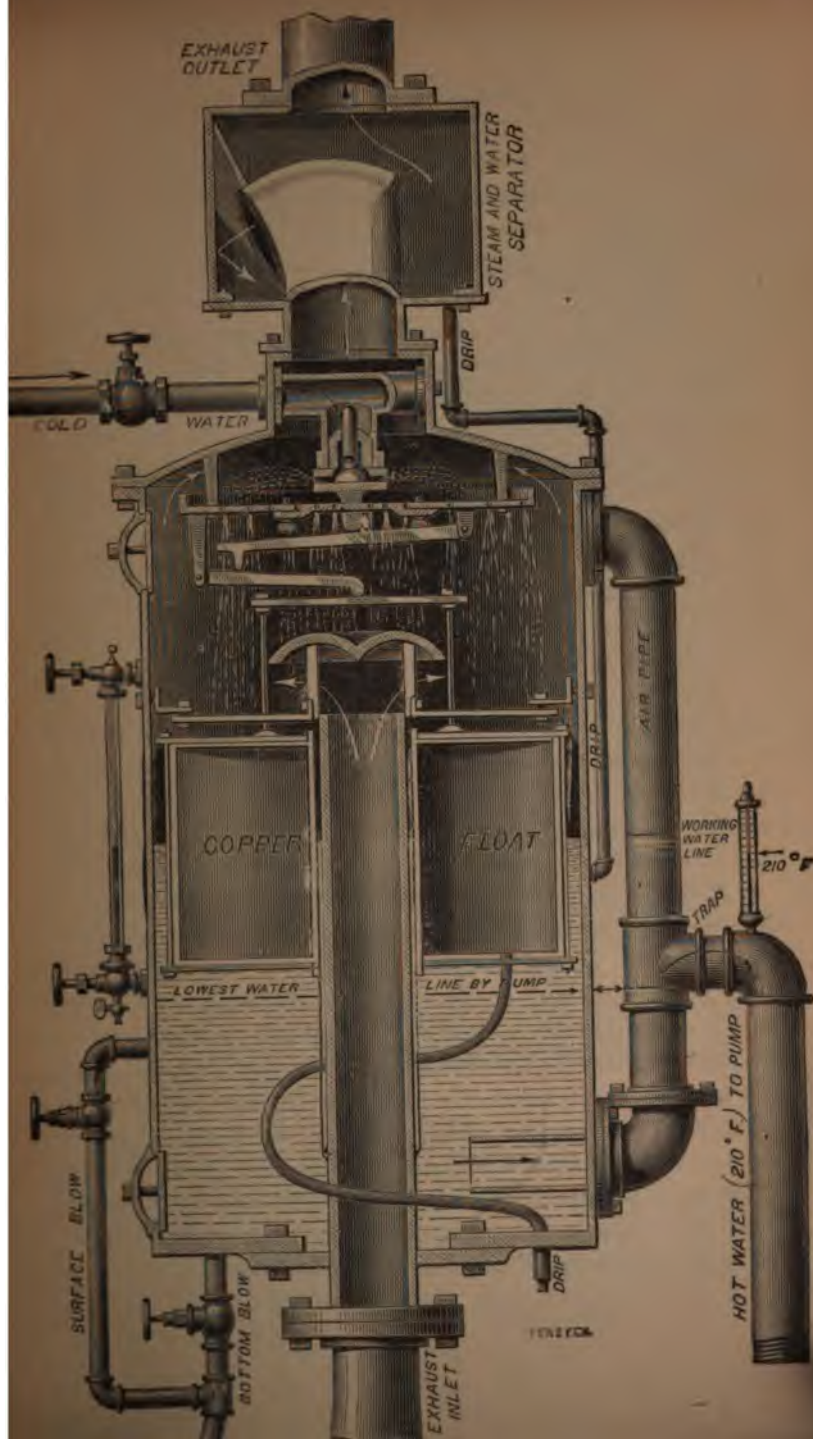
PRINCIPAL DIMENSIONS OF STILWELL'S LIME-EXTRACTING HEATER AND FILTER COMBINED.

SIZE NO.	LARGEST ENGINE HEATER IS ADAPTED TO.	HEIGHT OF HEATER	DIAMETER OF HEATER	DISTANCE FROM CENTER OF STEAM INLET TO BOTTOM.	INTERNAL DIAMETER OF EXHAUST OPENINGS A AND B.	OUTSIDE DIAMETER OF FLANGES A AND B.	HOT WATER PIPE J.	COLD WATER PIPE C.	DISTANCE FROM HOT WATER PIPE J TO BOTTOM OF HEATER.
	IN. BORE.	FEET.	INCHES.	INCHES.	INCHES.	INCHES.	INCHES.	INCHES.	INCHES.
3	6	4	15	28½	2½	5	1	1	11½
4	9	5	20	33½	3	5½	1	1	13½
5	12	6	24	39½	5½	8½	1½	1½	17½
6	16	7	30	49½	7	10½	2	1½	20½
7	18	8	36	53½	8	11½	2½	1½	21
8	24	9	48	58½	10	13½	3	2	27
9	30	10½	48	72	11½	15½	4	2	27

Green's heater, as made by the Green Feed Water Heater Company, New York city, is shown in vertical elevation in figure 154. Its operation will be easily understood from the following description :

The cold water entering the heater by the pipe marked "cold water," passing through an open or poppet valve, as seen by cut, inside of heater, is thrown upon a perforated plate, through which it passes, falling in the form of rain or spray. The float operates upon said valve by compound levers, and so controls with ample force, automatically, any pressure of the water coming into the heater, allowing no more water to enter than is wanted by the pump for the boilers, or for other mechanical purposes. The exhaust steam enters at the bottom of heater through the large central pipe (which pipe corresponds in size with the exhaust pipe from engine), and striking against the disk seen at its top, is directed laterally against the falling spray of water, heating it almost instantly to boiling point. The surplus steam then passes around the perforated plate into the steam and water separating box, as seen at the top of heater. The hood or pipe inside of box deflects the steam against the sides and bottom, and by an expansion of the steam, drops to the bottom of box any water taken up from within the heater; the steam passing into the exhaust outlet is perfectly dry, while the water dropped from the steam, passes by a drip pipe to the body of the heater below.

The water in heater flows out to the feed pump through the large pipe on the right, to which is connected an air pipe, in consequence of which it will be noticed that the body of water in heater can not be pumped down lower than the line marked lowest water line by pump, as when such level or line is reached the pump takes in air and steam. This lowest pumping line of water, holding upon its surface any dirt or grease, is removed daily by the



pipe and valve on the left marked surface blow, while the collection of dirt at the bottom of heater is removed weekly by the pipe and valve marked bottom blow.

The float is constructed of copper on the outside, and is strengthened beyond the possibility of injury from either pressure or collapse, by a strong cedar barrel, well made and hooped, fitting the inside of float. The float thus constructed is perfectly reliable; but as an additional safeguard, a spiral brass tube (called in cut a drip), is coupled to and enters the bottom of float, and passing down through the bottom of heater, acts as a drip in case of leakage, enabling the float to perform its duty until the leakage in float is greater than the capacity of drain by the drip. Furthermore, the atmosphere passing in and out of float by such brass tube, it becomes the means of safety against any tendency to collapse.

An iron plate or apron is shown in cut just above the float, which protects the float from the pulsations of the steam, and so, not only aids the float in keeping the water quite below, but the drops of water falling upon it from above, rebound, giving the steam another chance of heating it before it passes off at the sides to the well below.

A water gauge and thermometer are furnished to each heater, the thermometer standing on the elbow of pipe to feed pump. Such thermometer is put in position that it may bear testimony constantly that the heater produces a uniform temperature of 210° Fahrenheit, or whatever may be the highest temperature possible by exhaust steam. Two large hand holes are provided in the upper part of heater, by which the valve and upper working parts of heater are reached with great readiness and efficiency. Also one large hand hole near the bottom, by which the drip pipe attached to float, and any accumulation of dirt in bottom of heater, can be readily handled.

The "Victor" heater, by Wm. Allen & Sons, Worcester, Mass., is shown in elevation in figure 155, and is a modified form of the tubular heater so well known to steam users.

This heater can be used with exhaust steam where there is sufficient or excess of exhaust, also with exhaust and live steam combined, in a place where large heating capacity is required and but a small engine to run; or with live steam alone, for heating water for boilers used in heating large public buildings, hotels, etc. The greatest gain is made in fuel where exhaust steam only is used, but the heater will work equally well under either condition. When using exhaust, the steam, before leaving the heater, must pass through three sets of tubes, each set being the length of the heater, and each of greater area than the largest exhaust pipe, so that the engine is relieved and all liability of back pressure prevented.

The heat causes the mineral and vegetable matter, which is held in solution by the water, to settle in the bottom of the heater, and it is blown out through the pipe in the center of the bottom, at the same time opening the



FIGURE 155.

live steam pipe in the top head so as to force the water down in a body, blowing out all sediment and dirt through the direct valve, which is easily reached, so that the work of purifying the water is attended with but little labor, and the fireman will prefer to use the heater and keep the boilers clean, rather than allow the sediment to settle in the boilers, and be obliged to remove it by chipping and picking. The use of the heater prevents, in a degree, the formation of scale in the boilers. The heater delivers the water pure, at a temperature as high as 210° Fahrenheit, using only a portion of the exhaust steam, and does not interfere with the steam for heating.

Stead's circulating generators for steam boilers, as manufactured by Ironclad Manufacturing Company, Brooklyn, New York, is shown in figure 156. Its arrangement and operation is as follows:

A A is a series of heavy lap welded pipes, connected by return bends resting on bearers and forming a continuous close coil under the boiler, from bridge wall to back connection, making a chamber in which the combustion of gases from furnace is maintained and the flame held in close contact with boiler until it strikes the deflecting wall, which causes it to pass to under side of pipes, through which it returns into back end of boiler; by this means the heat is equalized on coil and sufficiently retarded to secure full effect on boiler. The feed water enters the coil by pipe M and its connections, under the same conditions as to heat, etc., that it previously entered the boiler, and in its passage through coil it is heated to a temperature ranging from 240° to 310°, and enters the boiler through pipe I, as combined steam and water. J is a stop valve between coil and boiler, and K is a blow cock for clearing the coil. When the feed is stopped, the pressure in boiler gives full opening to check valve L on pipe P, and the

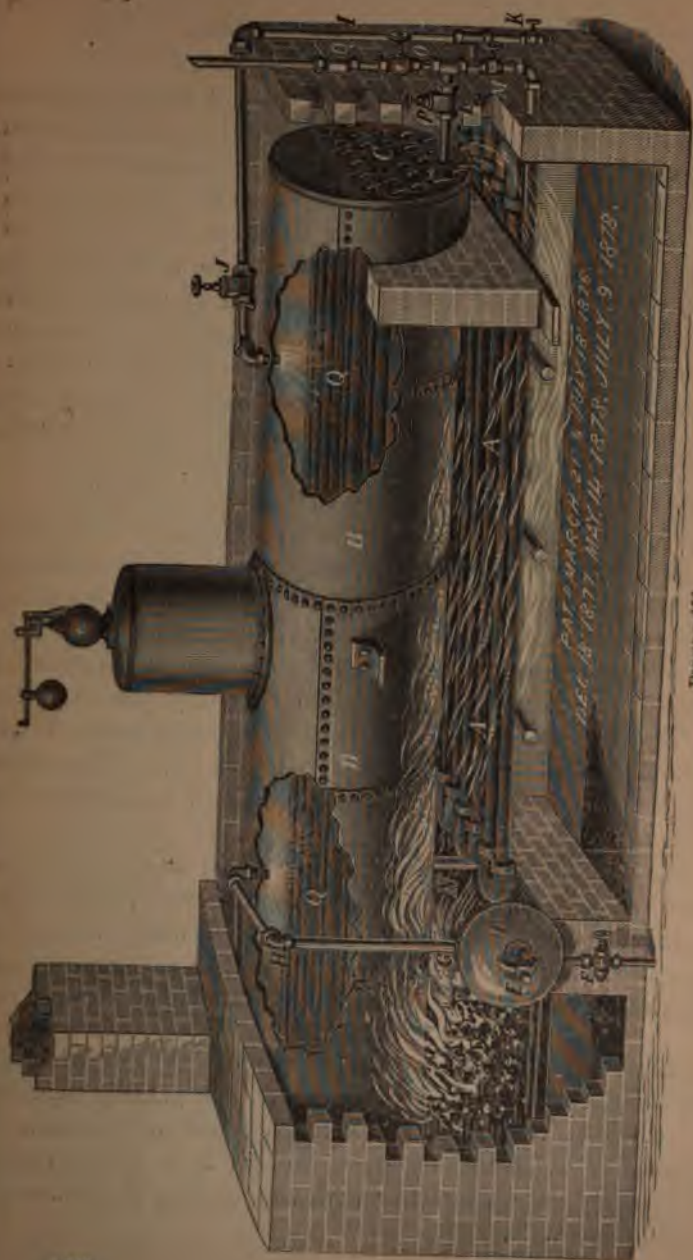


FIGURE 156.

water from boiler passes down into the coil, through which by its increasing temperature, it circulates with great rapidity to the boiler. By this means the coil is always filled with water, and can not be burned. The check valve was designed for this purpose; it gives full and direct opening to pipe, and can not stick or fail to work perfectly.

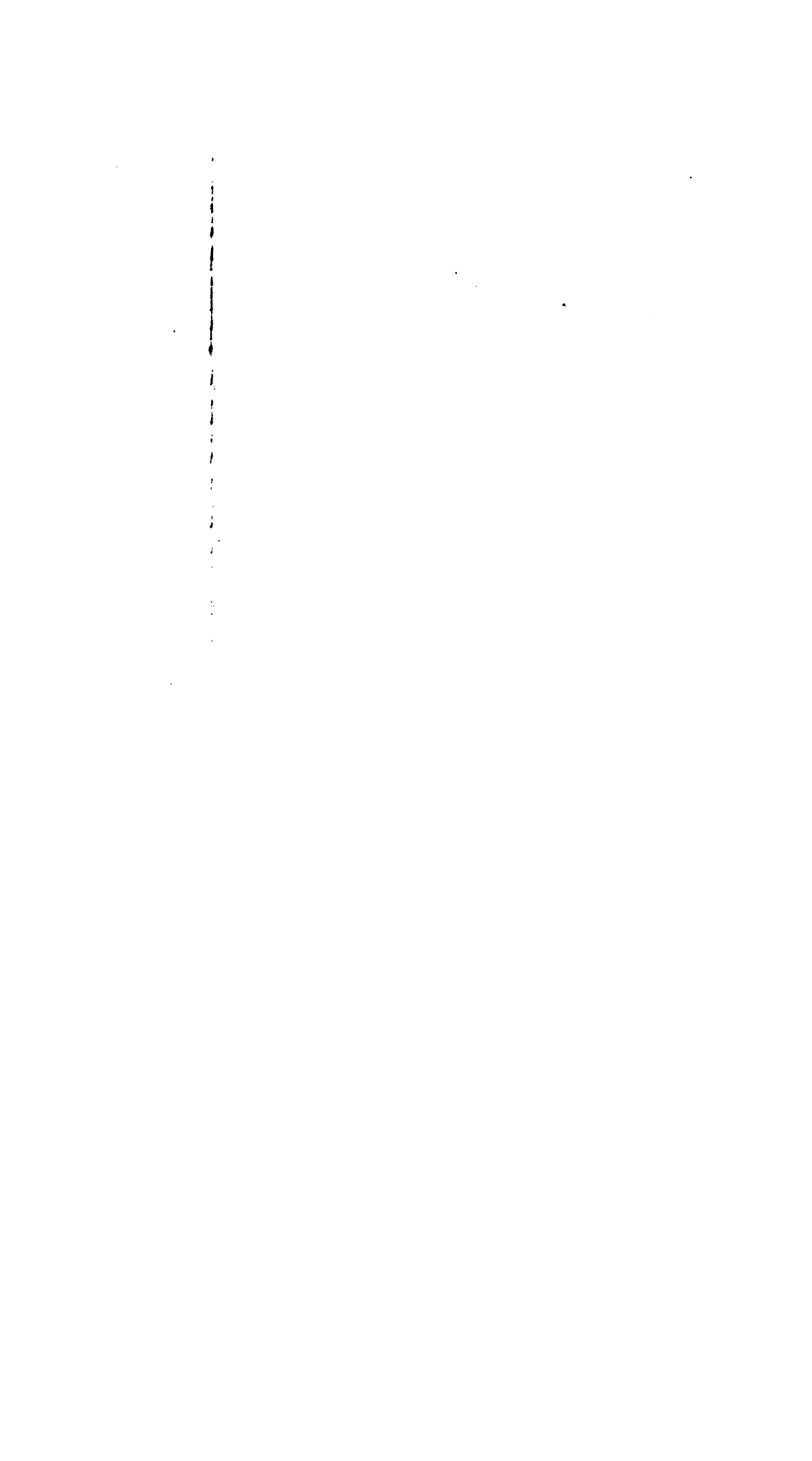
D is a riveted cast steel drum, taking the place of brick bridge wall, which is lowered to admit it. The water from bottom of boiler passes through pipe N to drum where its temperature is raised much higher than that of the boiler, to which it returns nearly all steam, through pipes G H. By this means the intense heat at the bridge drum is utilized, and a rapid and continuous circulation is maintained. The lime and other impurities in the water can not settle and form scale, but pass down into the drum from which they do not return to boiler, and are readily blown out through pipe F or removed at hand hole E.

The blow off valve connected at this point is opened a minute or two each day, and in this way the sediment (before it hardens into scale) is as effectually blown out as if the entire amount of water were blown off. This is done while steam is being generated, and can be repeated as often as required.

As a feed water heater, this coil in the combustion chamber possesses advantages seldom secured, and results in raising the temperature of the feed water nearly fully up to that in the boiler. The rapid and continuous circulation of water keeps the attachment free from scale.

Economizers—This word, used in connection with the apparatus employed to recover waste heat passing off from the flues of the boiler into the chimney, is somewhat unfamiliar to American ears, though it is by no means new to those at all familiar with the leading English engineering journals.





An economizer is usually understood to be an assemblage of pipes in the smoke passage between the boiler and the chimney. Its object is to abstract heat from the escaping gases and turn it to useful account in heating the feed water. It would naturally be supposed that the boiler itself would be the best apparatus for heating water, and that little or nothing would be lost by pumping cold water to the boiler.

This is not the case. Boilers, as usually constructed, are good steam generators, and act most efficiently when the feed water is of high temperature, nearly or altogether approaching that of the water in the boiler. Such an apparatus is far from being a good heater, because the temperature of the escaping gases, when leaving the tubes, is so nearly that of the contents of the boiler, that little or no heat is given up by the gases. In a properly made economizer, the cold water enters at one end of the apparatus, and in passing through it takes up heat as it goes.

The temperature of the escaping gases is not far from 600° , on an average. If the steam pressure in the boiler is 75 pounds, the temperature will be 320° , or a difference of 280° . The rate of transfer of heat from the gases to the water within this range of difference will be slow, and hence will require a large exposure of surface to render it of any value.

An economizer is not to be regarded as merely equivalent to lengthening the boiler. The functions of the two are entirely different. Steam can be generated only at certain temperatures, and when the temperature of the water falls below that due to the pressure of steam, ebullition ceases until the steam pressure is lowered to the corresponding temperature.

The efficiency of the economizer is due to the fact that the temperature of the water within it is not the same throughout. The feed should enter at a point furthest

removed from the boiler; it here encounters the coolest gases, and, in its flow through the economizer, it takes up more and more heat, growing hotter as it advances, and is finally fed into the boiler considerably above the atmospheric boiling point.

The only circulation which an economizer should have, is that due to the action of the feed pump, and the pipes should be as small as is consistent with good and safe construction

An economizer, by Babcock & Wilcox, New York city, is shown in figure 157, and is, in some respects, an improvement over those in general use in England. It consists of a series of vertical tubes placed in a brick chamber, which forms part of the flue between the boiler and the chimney, and through which all the hot gases are caused to pass. These tubes are connected at top and bottom with horizontal tubes, the lower row of which are connected to a mud drum, and the upper row are connected together at the end diagonally opposite to the mud drum. The feed water enters at one end of the mud drum, and passes out at the opposite end of the upper connecting pipe. It will be seen that the water has the same distance to go, and the same resistance to encounter in whichever of the vertical pipes it may travel, and that, therefore, it will flow fastest where its gravity is least, or directly as its temperature, and only the hottest portion will be discharged. The hotter gases, filling the upper portion of the chamber, come in contact with the water at its highest temperature, so that it is possible to heat the latter very nearly to the temperature of the escaping gases before it flows to the boiler.

Ample provision is made for cleaning the interior of the vertical and horizontal tubes, and the mud drums by means of hand holes with metallic joints opposite the ends of each tube. This is important, as in most hard water

sediment will form in the economizer more readily than in the boiler.

By means of a direct flue to chimney, the economizer may be cleaned without stopping the boilers.

Mechanical scrapers, worked from above, are provided for removing deposits of soot from the exterior of the tubes, the soot falling into a chamber below, from which it may be removed at convenience.

All joints in the construction of the economizer are metallic, no packing of any kind being used, except for the large hand holes in the mud drum, and the parts are so put together that any one part may be removed and replaced without disturbing the other parts, and with comparatively little trouble. The tubes are made of cast iron, the experience of years having proven that this is much the best material to resist the tendency to corrosion arising from the condensation of vapors upon their exteriors. Wrought iron has been found utterly unsuited to the purpose.

Covering boilers and pipes—This is quite necessary, in order to save a great amount of heat which would otherwise be lost by radiation. There are quite a number of boiler coverings and cements, for this purpose, in the market. These are not all good. Figure 158 is a representation of a section of pipe, as covered with the *Asbestos air chamber covering*, under the patent of H. W. Johns, New York city. These coverings are formed as follows:

First apply the Asbestos lining felt to cover all surfaces, two thicknesses. It may be cut in lengths of one inch more than twice the circumference of the pipes, and wound twice around in sections, fastening each with a single turn of twine, then cut the hair felt crosswise of the sheet in strips, one inch larger than the circumference of the covered pipe, and bind firmly over the lining felt with twine, winding spirally four or five turns to the running

foot; next, cut the non-porous sheathing crosswise of the sheet, in lengths two or three inches larger than the circumference of the hair felt. Tie temporarily, and paste the lap with common flour paste, and apply carefully so the surface will be smooth. This, when finished with a



FIGURE 158.

fire proof paint, forms the single chamber, which is suitable for small pipes, or where less than 40 pounds of steam is used.

To form double or triple chambers, add alternate layers of hair felt and non-porous sheathing. To finish these coverings, paste bands of non-porous sheathing about two inches wide over the joints, being careful to put them on true. This adds to their strength, and forms a handsome finish.

ws and tees should be covered with canvas or drill-
re finishing with the non-porous sheathing, which
lways overlap the can-
fter the pasted joints
finish the whole with
f paint.

e instructions also ap-
vering boilers or other
rfaces, except, that the
ould be covered with

This covering has, so
luced very satisfactory
n general pipe work.

her kind of covering,
ctured by the Chal-
ence Company, New
ty, is shown in figure
ts application to boil-
consists, first, in leav-
air space or dead air
between a wire cover-

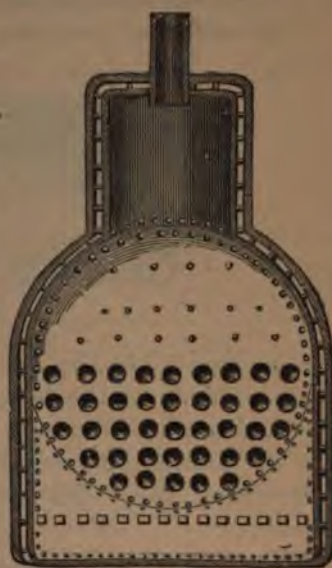


FIGURE 159.

the surface covered ; second, in the keying of some
material on the wire cloth ; and third, in giving a
check to radiation by the confined air and the non-
composition. There are numerous other advan-
which might be mentioned, but the above named are
t prominent. The air space is made by taking
fire cloth, to which is fastened, every four or five
a stud one inch or more in length. The wire cloth
fitted over the surface to be covered, the studs
it the necessary distance off. The plastic material
applied, in two or more coats. The first coat partly
tes the meshes of the wire cloth and keys itself,
g a strong, durable li. The second coat makes

a smooth, even finish, which may be painted, grained, or varnished, as may be desired.

There are many objections to applying a covering direct to the surface of the boiler, for it has been found, especially



FIGURE 160.

in marine boilers, that, when so covered, the inside as well as the outside of the boiler rapidly scales. The air space method, we are informed, is not open to these objections. On the contrary, it keeps the iron clean and bright, besides preventing the radiation of heat and condensation of steam.

Figure 160 shows the application of the same covering to steam pipes. Tests made with this covering show it to be an effective means of preventing loss by radiation.

CHAPTER XV.

SAFETY APPARATUS.

Safety Valves—Dangerous Connections—Combined Safety and Stop Valve—Richardson's Safety Valve—Ashcroft "Pop" Valve—Crosby Safety Valve—Lunkenheimer's Safety Valve—Kunkle's Safety Valve—Pressure Gauges—Bourdon's Gauge—Lane's Gauge—Diaphragm Gauges—Holt's Gauge—Post & Co.'s Gauge—Edson's Recording Gauge—Gauge Cocks—Glass Water Gauges—Fusible Plugs.

The safety apparatus commonly attached to steam boilers consists of a safety valve, gauge cocks, glass water gauge, pressure gauge and a fusible plug.

Safety valves—A safety valve should be of such size as will enable the escape of all the steam which the boiler is capable of making, without increasing the pressure in the boiler over ten to fifteen per cent above that to which the valve may be loaded.

RULE 1—The United States regulations require that safety valves for ocean and river service "shall have an area of not less than one square inch for each two square feet of grate surface, when the common safety valve is employed.

"**RULE 2**—But when safety valves are to be used, the lift of which will give an effective area of one-half of that due the diameter of the valve, the area required shall not be less than one-half of one square inch to two square feet of grate surface."

The grate surface seems to be, all things considered, the best unit of measurement for determining the size of safety valves. The ordinary rate of combustion may be placed at, say 14 pounds of coal per square foot of grate, and the rate of evaporation may be taken at ten pounds of water per pound of coal, as the maximum. There are many formulas bearing on valve proportions, but those given in the United States regulations are easily remembered and ample in size for any requirement.

The grate surface for a 48-inch boiler, as given on page 246, is 20.6 square feet; this would require an area 10.3 square inches for a common valve, or $3\frac{1}{2}$ inches in diameter. If figured by the rule in the next paragraph, the area would be 5.15 square inches, or $2\frac{1}{2}$ inches diameter.

The writer does not recommend safety valves of a greater diameter than four inches. The area of a valve increases as the square of its diameter. The circumference increases directly as the diameter. The escape of steam is around the circumference, and it will be understood, of course, that a point would soon be reached in which the area would be of little account if carried to large diameters and figuring on ordinary valves. For example, if the grate area required a common valve eight inches diameter, it would have a circumference of 25.13 inches; the same area would be furnished by four 4-inch valves, the combined circumferences of which would equal 50.26 inches, or twice the circumference for the same area. An 8-inch valve is an extreme case, but it illustrates the point.

Each boiler should have its own safety valve. It should be connected directly to the shell, and in no case should there be a stop valve between it and the boiler. The writer happened to be in a large establishment not long since, in which he saw the boilers connected together by means of a steam drum having stop valves in the boiler connector

and one safety valve on the top of the drum to serve for the two boilers. The attention of the owners was at once called to the great danger which might accrue from an unintentional closing of both valves. In looking over an annual report of the Hartford Steam Boiler Inspection and

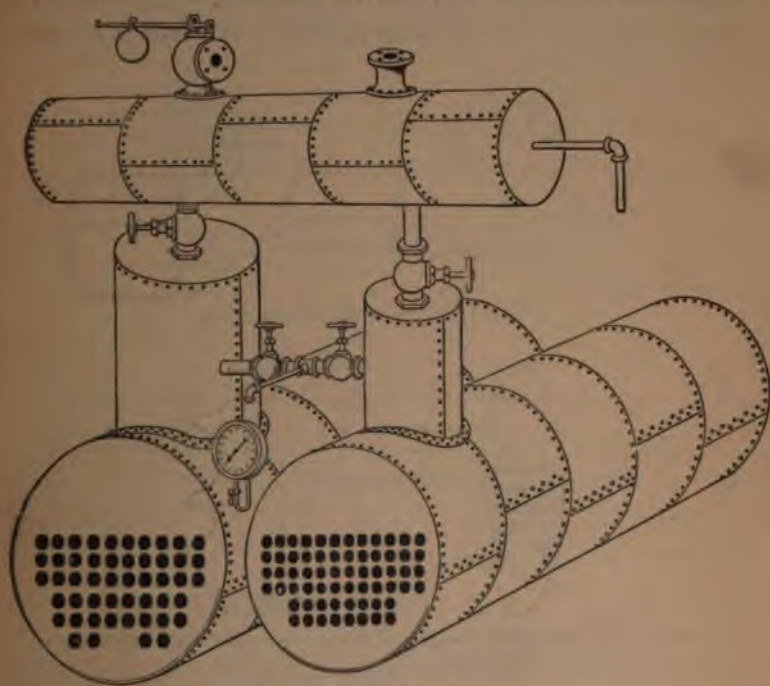


FIGURE 161.

Insurance Company, the writer saw an engraving of a precisely similar connection, with the record of the disastrous results following. Through the courtesy of Mr. J. M. Allen, president of the company, the writer is enabled to place before the reader copies of the engravings referred to. Figure 161 shows the original condition of the boilers:

“It appears that for some reason one boiler had been shut off, and the steam gauge between the boilers had been

removed for repairs. The boiler was fired up, and a destructive explosion occurred. Fortunately, no lives were lost. There are many boilers through the country set in this way, and serious accidents have occurred and will occur so long as this practice is followed. Portions of the boiler were thrown from 300 to 700 feet. The following figures will show the manner in which the iron was torn:

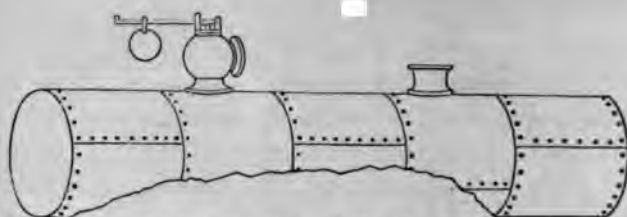


FIGURE 162. The top of the steam drum.

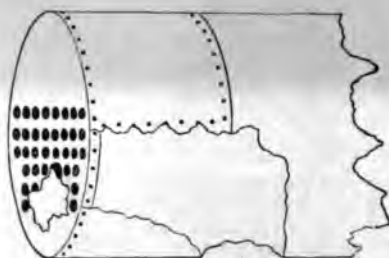


FIGURE 163. Rear end of the left hand boiler, which was thrown some 225 feet.

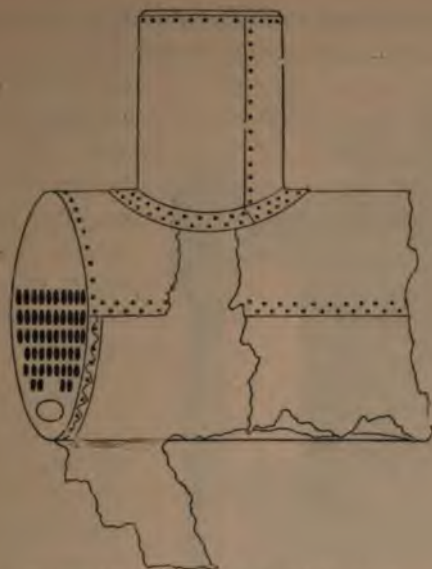


FIGURE 164. Front end of the left hand boiler.

A combined safety and stop valve, by the Atlas Engine Works, Indianapolis, Indiana, is shown in figure 165. By an inspection of the engraving it will be seen that the stop valve may be opened or closed without, in any manner,

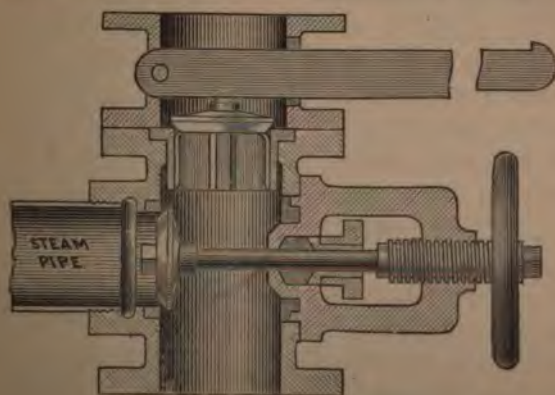


FIGURE 165.

affecting the safety valve. The valve is shown with a lever attachment, but a spring may be used instead. This is an

excellent form of construction, and will enable any particular boiler in a battery to be shut off from the others, and, in the event of steam being raised, it will take care of itself.

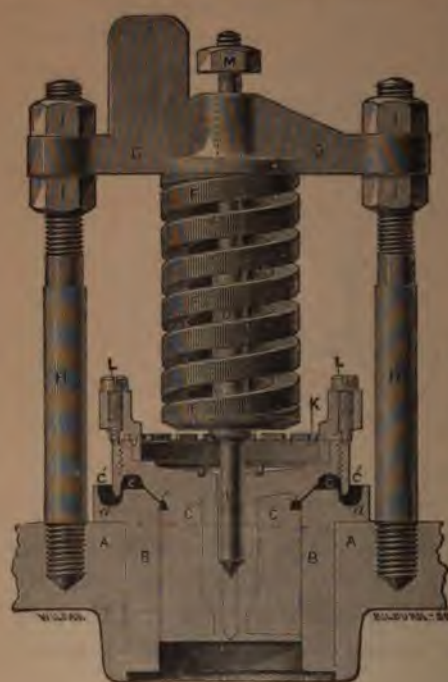


FIGURE 166.

The Richardson safety valve is shown in figure 166. This engraving shows the usual mode of attaching the valve to the dome head of a locomotive boiler. A A, being the cast-iron head; B B, a gun metal bushing; C, the valve fitted with an annular adjustable lip C'. The valve is lifted

from its seat by the pressure which, in escaping around the circumference of the valve, impinges against the interior of the chamber formed by the projection of the valve, and by this adjustable lip, which, in effect, increases the area of the valve not only, but the steam acts against it with much greater force after it lifts it from the seat than before. Notches, K, are provided in the ring for adjustment, and secured by screws, L. The tension of the spring, F, is regulated by the nuts, I I, and cross head, G.

A self contained valve and case for stationary and marine boilers, without the adjustable lip, is shown in fig-

re 167; its action is the same as the one already referred to. These may be fitted with a lock up device, as shown; the valve may be set at any required pressure, and the case locked up, and thus preventing access to the valve or spring, except to those having the key. The lever may be used to test the valve, but can not be made to bear down upon it.

The Ashcroft "pop" safety valve—This valve is shown in elevation in figure 168, and in partial section in figure 169, which shows one of the distinctive features in the valve construction—that is, the nickel seat. The valve seat, and that portion of the valve which bears upon it, are made of hard nickel bronze, which may be made as hard as steel, and yet suffers no corrosion by the action of either the steam or the air. The "pop" receives its name from the sound it emits when suddenly opened under

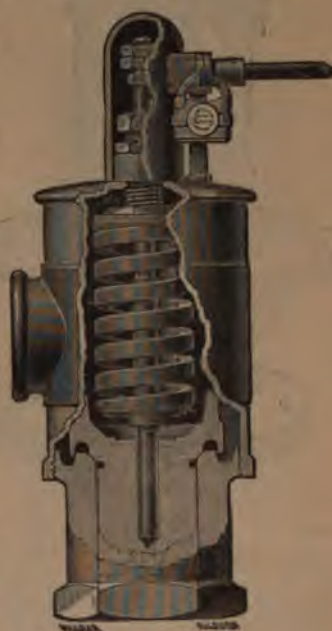


FIGURE 167.

pressure. This can also be made a lock up valve by making a dome to cover the upper works, and bolting to the flange at A D.

A special valve for portable and other small boilers is shown in figure 170, and is in all essentials the same as those already described.

The Richardson and the Ashcroft patents are now controlled by one company, under the name of the Consolidated Safety Valve Company, Boston, Mass.

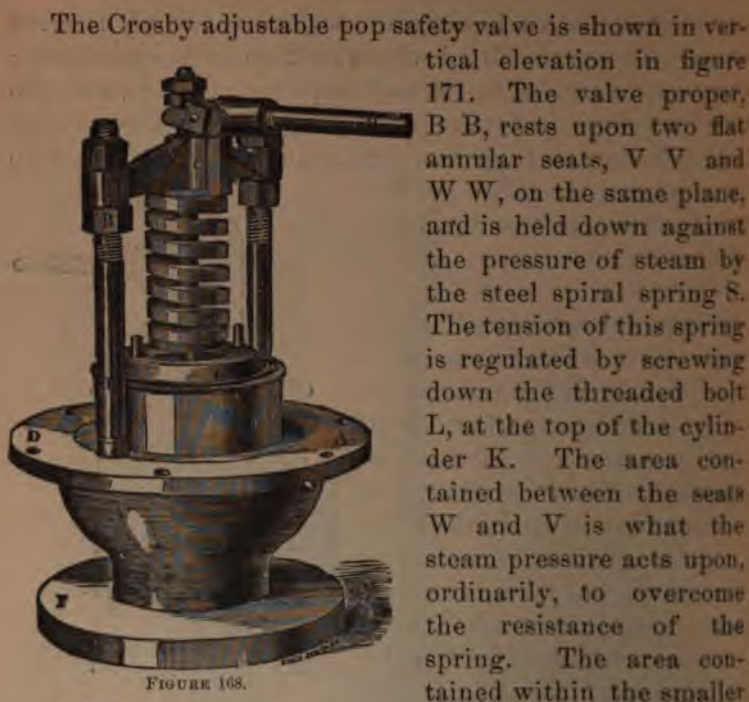


FIGURE 168.

The Crosby adjustable pop safety valve is shown in vertical elevation in figure 171. The valve proper, B B, rests upon two flat annular seats, V V and W W, on the same plane, and is held down against the pressure of steam by the steel spiral spring S. The tension of this spring is regulated by screwing down the threaded bolt L, at the top of the cylinder K. The area contained between the seats W and V is what the steam pressure acts upon, ordinarily, to overcome the resistance of the spring. The area contained within the smaller seat, W W, is not acted upon at all until the valve opens. The large seat, V V, is formed on the upper edge of the shell or body of the valve A A. The smaller seat, W W, is formed on the upper edge of a cylindrical chamber or well, C C, which is situated in the center of the shell or body of the valve, and is held in its place by four arms, D D, radiating horizontally at right angles to each other, and connect-



FIGURE 169.

ing it with the body or shell of the valve. These arms are hollow and form four passages, E E, for the escape of the steam or other fluid from the well into the air when the valve is open. This well is deepened so as to allow the wings, X X of the valve proper to project down into it far enough to act as guides. The area of the apertures, at the outer ends of the passages through the arms is reduced more or less at will, by screwing up or down the



FIGURE 170.



FIGURE 171.

adjustable ring G G. Action of the valve when working under steam: When the pressure under the valve is within about one pound of the maximum pressure re-

quired, the valve will open slightly, and the steam will escape under the larger seat into the cylinder surrounding the spring, thence into the air; the steam is also forced under

the smaller seat into the well and thence through the passage in the arms into the air. As soon as the pressure attains the exact maximum point, the valve will be lifted so high as to force the steam into the well faster than it can escape through the apertures in the arms; a pressure will then accumulate under the inner seat, which will be in excess of what was required to overcome the increasing resistance offered by the spring, and acting upon the additional area presented, at once forces the valve wide open and rapidly relieves the boiler. This pressure under the inner seat is of itself differential. The valve then at once slowly settles down and the pressure under the inner seat as slowly diminishes, and so continues until the

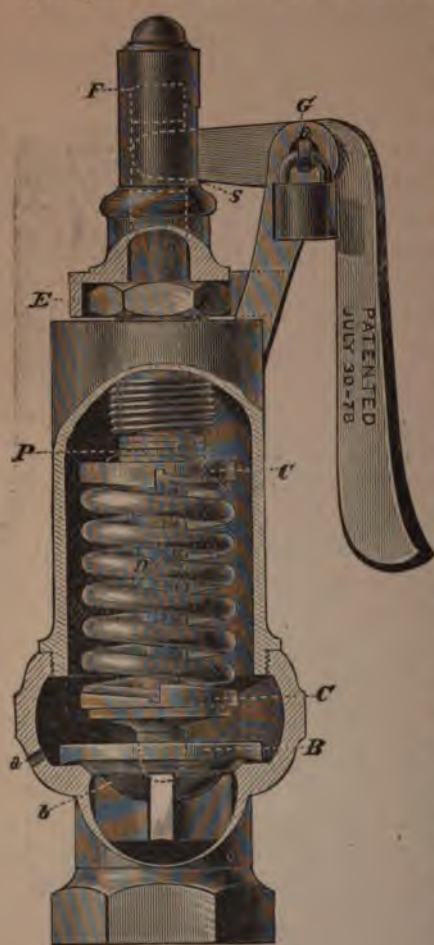


FIGURE 172.

area of the opening, under the smaller or inner seat, is less than the area of the apertures in the arms for the escape of

the steam; the pressure then ceases and the valve promptly closes. The point of opening can be readily changed while under steam by screwing the threaded bolt at the top of the cylinder, either up or down; and the point of closing is as easily adjusted, by screwing up or down the ring surrounding the outside shell or body of the valve. The seats of this valve are flat and do not wear out and leak so readily as beveled seats.

This valve is made by the Crosby Steam Gauge and Valve Company, Boston, Mass.

An adjustable lock up safety valve by F. Lunkenheimer, Cincinnati, Ohio, is shown in figure 172.

The valve B has an annular projection beyond the seat and fitted on its upper side with a concave step to receive the point of the stem shown above it.

The manner of loading the valve is novel and simple, so no mistakes are likely to occur. Every valve is set to ninety pounds and so marked, unless otherwise ordered. The change of the load is effected by a series of washers P between the spring plate C and set screw E.

Each washer added will increase the load ten pounds; each washer taken off will reduce the pressure ten pounds.

The valve when locked can be lifted at will, but can not be loaded, being prevented by a shoulder in bonnet at S. When taking the valve apart, remove the lock, lever and bonnet, and raise the set screw E, so as to relieve the spring, then insert the lever H in the fulcrum, and the casing or shell is easily unscrewed.

Before adding the bonnet, keep the set screw well down to its shoulder.

A lock up safety valve by E. B. Kunkle, Fort Wayne, Ind., is shown in figure 173. The spring is set between two tapered points, enclosed in the valve with sufficient room to allow it to curve when weighed down, which prevents all friction, securing the spring from being over-

heated by the steam so as not to weaken it; the top end of the valve is enclosed by a flange underneath the cap, thus protecting the spring from the steam, sediment and cinders, when used on locomotives, keeping it entirely clean at all times, making it reliable under constant action, which can not always be the case with springs exposed to the steam and weather.

TABLE LXXXXIV.

DIAMETERS FOR SAFETY VALVES, ACCORDING TO RULES 1 AND 2,
PAGE 383.

AREA OF GRATE SURFACE, IN SQUARE FEET.	DIAMETER FOR COMMON VALVE, BY RULE ONE.	DIAMETER FOR VALVE, BY RULE TWO.
	INCHES.	INCHES.
5	$1\frac{1}{4}$	$\frac{7}{8}$
6	2	1
7	$2\frac{1}{8}$	1
8	$2\frac{1}{4}$	$1\frac{1}{8}$
9	$2\frac{3}{8}$	$1\frac{1}{8}$
10	$2\frac{1}{2}$	$1\frac{1}{4}$
12	$2\frac{3}{4}$	$1\frac{3}{8}$
14	3	$1\frac{1}{2}$
16	$3\frac{1}{4}$	$1\frac{5}{8}$
18	$3\frac{3}{8}$	$1\frac{3}{4}$
20	$3\frac{5}{8}$	$1\frac{3}{4}$
22	$3\frac{3}{4}$	$1\frac{7}{8}$
24	$3\frac{7}{8}$	2
26	4	2
28	$4\frac{1}{4}$	$2\frac{1}{8}$
30	$4\frac{3}{8}$	$2\frac{1}{4}$
32	$4\frac{1}{2}$	$2\frac{1}{4}$
34	$4\frac{5}{8}$	$2\frac{3}{8}$
36	$4\frac{3}{4}$	$2\frac{3}{8}$

The uniform bearing of the valve upon its seat by reason of the long ribbed chamber prevents the valve from capping upon one side and causing the steam to cut away the seat.

The outside regulator can be adjusted when the valve is blowing off, so that it will act with a sudden report, or open and close gradually, with little or no report. It is provided with a screw bolt resting on the plate on top of the spring, and jam nut holding it firmly to its place; the top of the bolt being adapted to receive a lead seal, which makes it doubly safe from being tampered with.



FIGURE 173.

Pressure gauges properly belong to the safety apparatus of a boiler, although performing no other service than simply to indicate the pressure within the vessels to which they are attached. As great reliance is often placed on the steam gauge, it is of the utmost importance that it be of approved design and of the very best quality. Steam gauge pipes should not be attached to a steam pipe, but to the top of dome, drum or boiler.

It not unfrequently happens that the safety of an entire establishment depends upon the reliability of this instrument and on the safety valve. The latter is not always convenient of access, and is liable to be neglected; the steam gauge, on the contrary, is always placed in some convenient position, and is consulted every few minutes when the boilers are in use. The writer has known of instances in which gauges had been in use for a long time, and upon submitting them to a test, many were found to


be so far in error and so unreliable in their readings as to be utterly worthless; in one instance in particular, a gauge marking nearly twenty-four pounds per square inch too little, the pointer starting from 0 in every case, when relieved of pressure. This was a finely finished, high priced gauge, and was believed to be correct until it was submitted to a test.

Every steam gauge should be tested at least once a year, to be sure that it indicates the pressures correctly.

Spring gauges have for many years past been in very gen-



FIGURE 174.

eral use in this country, most of them being either direct copies or some modification of the original Bourdon gauge, illustrated in figure 174. This gauge consists of a curved tube, usually of brass, though sometimes of steel, having an elliptical cross section, thus: . One end of this tube is rigidly fastened to that por-

tion of the instrument by which communication is had with the steam pipe; the other end is closed and left free to be influenced by the pressure within the tube. The action of this internal pressure on the tube is to change its transverse section from an ellipse to that of a circle. This change of section disposes the metal differently in the tube, and has a tendency to straighten it, and being fixed at one end, the other moves outward from the

original position occupied when free from pressure. The distance at which this free end of the tube will move depends entirely upon the pressure within it; advantage is taken of this movement to record on a circular dial the pressure found necessary to produce certain movements. These curved tubes may be made of any desired tension, the thinner the tube the less will be the pressure required to produce a movement. The thicker the tube the greater will be the pressure required, so that gauges may be constructed on this principle indicating very slight pressures above the atmosphere, or, by the suitable selection



FIGURE 175.*

of a tube, they may be made to register the highest pressures of the most powerful hydraulic presses.

Steam gauges usually have a siphon attached to prevent the steam entering the tube. This siphon collects a body of condensed water within it, against which the steam acts on the one side, and through its action the pressure is communicated to the elliptical tube. During the winter months the tubes in the Bourdon gauges are not unfrequently split, or else so disturbed by the freezing of the water as to produce false readings. This defect in the original Bourdon gauge was wholly remedied in the modified construction designed by Mr. Lane, whose gauge is shown in figure 175.

*This engraving, and the one preceding, are from designs by the American Steam Gauge Co., Boston, Mass.

This gauge differs from the one just described in so combining the indicating tube with the pipe through which the pressure is transmitted, in such a manner that the length of the tube in either direction from its junction with the steam pipe shall not exceed a semi-circle, and placing the tube in such a position that it shall descend at any point towards its junction, and thus drain any water it may contain back into the pipe.

By joining the pipe from the boiler with the indicating tube at a point nearly midway between its two ends, and bending this tube so that the ends shall be nearly over the points where its two branches are rigidly supported, the tube is rendered less sensitive to the vertical shocks to which it may be subjected, especially in locomotive use.

By bending the two portions of the indicating tube symmetrically, or nearly so, upon the opposite sides of a vertical line, and then connecting the two extremities of the tube with the lever, as shown in the engraving, will prevent the horizontal vibrations of the tube from being transmitted to the index hand, the lever being pivoted to the indicating tube, and is not attached to the case, this latter being an important feature in its construction.

Diaphragm gauges, are those in which there is a cavity or chamber in some portion of the mechanism (usually immediately below or in the back of the case), in which the pressure is applied on one side of a flexible partition, the effect of which is to "dish" it in the center; this force is opposed on the other side by a spring, or other device; in those gauges in which the partition (the diaphragm) is not strong enough to resist the pressure, a movement of the diaphragm will take place. This movement corresponds to certain pressures which are to be marked on the dial of the gauge.

This principle of construction admits of almost numberless combinations, and as a result scores of these gauges have been designed, ranging everywhere in excellence from good to bad. The principal defect in these gauges, where a metal diaphragm is used, is, that continued use soon destroys the elasticity of the diaphragm in those gauges where its movement in the center amounts to $\frac{1}{8}$ inch or more. Many experiments have been made from time to time, to determine the best system of corrugations for the diaphragm, for upon its efficiency and durability depend the value and reliability of the gauge itself.

Figure 176 is a modified form of a diaphragm gauge by Mr. John P. Holt, Cleveland, Ohio, in which 1 represents a brass plunger which rests upon a flexible diaphragm, shown immediately below it. The upper end of this plunger is attached to a semi-circular spring



FIGURE 176.

which extends across the case as shown at 2; a lever 3, having a fulcrum attached to the case, is operated by the action of the plunger 1, and thus through the action of the intermediate mechanism, shown in the center of the engraving, the upward motion of the plunger is indicated on a circular dial, and corresponding pressures read off in the usual manner.

The prominent feature in this gauge is the placing of the spring 2 inside of the case and out of contact with steam or moisture. The rise of the brass plunger is, in

Mr. Holt's practice, reduced to about $\frac{1}{16}$ inch. This gauge is quite sensitive in its action, and is well liked by locomotive engineers on account of its being able to withstand the jarring incident to railway service.

Figure 177 represents an internal front view of a diaphragm gauge by Post & Co., Cincinnati, Ohio. A por-



FIGURE 177.

tion of the follower D, is removed in order to show the position of the diaphragm, with reference to the mechanical movement which transmits the vibration of the diaphragm to the pointer or registering hand. This is better shown in figure 178, which represents a perspective sectional view of the whole mechanism of the gauge, with the exception of the pointer and graduated dial.

The steam enters the gauge at A and passes through into the chamber B; a diaphragm, C, is securely fastened

about midway in this chamber by screwing down the follower D firmly upon it. A thin, soft metallic gasket, shown by the parallel lines immediately below the section of the diaphragm at D, insures a tight joint, and prevents the steam passing through into the body of the gauge.



FIGURE 178.

The diaphragm is, of course, the important thing in any gauge of this description. Heretofore the great trouble has been experienced by the diaphragm yielding somewhat at the joints, by slightly drawing out, so that



FIGURE 179.

at different times, under the same pressures, the gauge would indicate different readings. This difficulty is overcome by making the surfaces of the joint to incline upward, so that when the follower D is screwed down upon the diaphragm and the steam impinges upon its lower surfaces it will tighten the metal within the joint instead of

permitting it to yield, and will at the same time lessen the possibility of any leak of steam. This detail of construction is shown in figure 179.

The diaphragm in this gauge is a radially corrugated steel disk, and is compensating in its movement, in that,



FIGURE 180.

when the pressure is applied, it has a motion which shows it to be sensitive to the most delicate pressure. This motion distributes the expansion or strain on the fibers of the steel throughout the whole area of the disc, instead of having, as in ordinary discs, all the strain come upon whichever corrugation may be the weakest.

This peculiarity of construction was put to a severe test during the Cincinnati Exposition of 1872, by subjecting one

of these gauges to an accumulating pressure until fifteen hundred pounds had been reached, and this, without "setting" the spring or affecting its accuracy.

Figure 180 is a full size representation of the follower D, and exhibits so clearly the registering mechanism as to need little or no description.

The lever E rests upon the center of the diaphragm, and is kept in contact with it by means of the spiral spring F.

The pressure of steam in the chamber B (see figure 178), presses the center of the diaphragm C, outward; this raises the lever E, which has indirect connection with the

sector and pinion, as shown. This pinion shaft carries the pointer indicating the pressure of steam on a graduated dial in the usual manner.

Recording gauges—The objects for which recording gauges are designed, among others, are,

1. To save life, by furnishing a monitor or check upon all those in charge of steam machinery, on land or water, inciting them to utmost vigilance and care.

2. To furnish an engineer means of obtaining an indubitable voucher of his capacity, as well as of his fidelity in the discharge of his responsible and important duties, and an impartial umpire to refer to when disputes or differences occur.

3. In cases of disaster, to fix the responsibility where it properly belongs.

4. To effect a saving in fuel by regulating the pressure, and thereby to diminish injurious strain on the boiler, and wear and tear of machinery.

5. To assist inspectors in arriving at the actual condition of the boiler, by showing the treatment it has sustained, as well as to enable them to judge to the fitness and reliability of engineers, when granting licenses.

6. To secure any desired degree of heat by maintaining the relative proportion of steam pressure necessary in factories, drying establishments, hotels, public schools, etc., where the proper regulation of the temperature is indispensable.

7. To afford reliable and tangible data for scientific and other investigations; for which purposes these "charts" or "steam logs" should always be dated and filed away, on removal, for future reference.

Figure 181 represents in elevation a time pressure and speed recording gauge, by M. B. Edson, New York city.

This gauge gives dial indications and accurate diagrams of all pressures; the charts define the time, and the safety

alarm is sounded whenever the limit specified shall be exceeded.

An "electro-magnetic alarm apparatus" will be furnished at a small extra cost, which rings a gong at the boiler whenever and as long as excessive pressure exists. The gong and magnet and batteries are shown in figure 182.

The gauge should be placed upon the shelf, supported by the brackets and firmly secured to a wall or partition of the office (or other room) where it is desired to place it, and about $4\frac{1}{2}$ feet from the floor. The aperture underneath (to receive the steam or other



FIGURE 181.

pressure) is intended for a $\frac{1}{4}$ -inch pipe with a bent tube or siphon.

The clock should be fully wound every day at the time of removing the portion of the chart traced upon.

The pencil lead is held by means of a slotted point in the thumb-screw (at the lower end of the spring holder) and may be pushed inward or withdrawn (after adjusting the screw), so as to give a clear tracing of every fluctuation indicated by the "pointers" on the vertical and upper scales.

The (toothed) friction plate upon the right hand reel should be released (by unscrewing the thumb-nut), in order that the chart traced upon may be removed and a fresh portion drawn forward. After the new end has been inserted in the slot in the reel and adjusted to the proper clock time, the nut should again be screwed down upon the reel



FIGURE 182.

just sufficiently to rotate the same, care being observed not to press so hard as to retard the movement of chart.

If the pencils become hard, soften by soaking in oil, bearing in mind that too great pressure upon the chart by the pencil will retard and may stop its movement.

Keep the chenille at the bottom of the glass dome pressed down to protect the instrument from dust.

When the gauge is used to indicate pressure of steam, water or oil, and is placed above the boiler or reservoir, deduct say one pound from the indicated pressure for every two feet in the difference in elevation; when below the level, add at the same rate.

The distance from the boiler longitudinally may be extended several hundred feet without materially affecting the indication of pressure.

The alarm movement is wound by a key from the front.

The alarm may be adjusted to ring at any point of pressure desired, by means of the long screw, which will be seen immediately behind the dial.

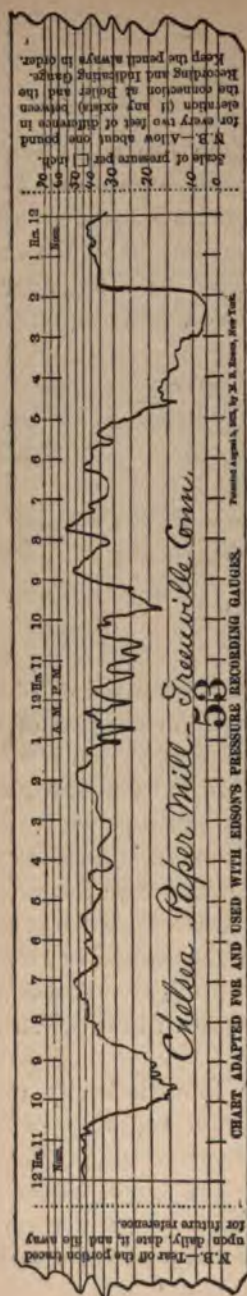


FIGURE 183.

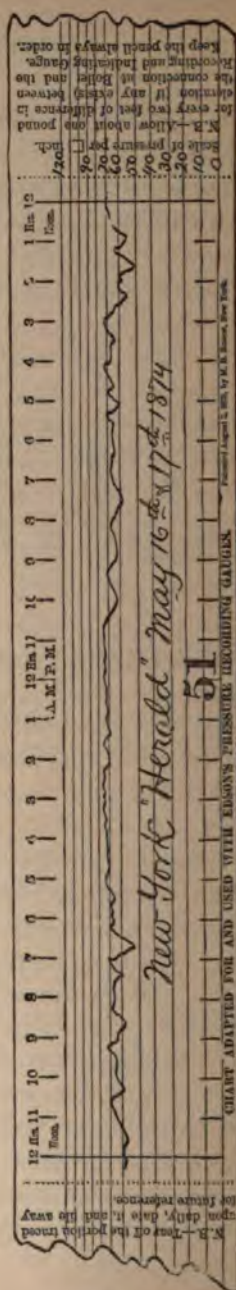


FIGURE 184.

The horizontal lines on the chart generally indicate every ten pounds of pressure, each chart being specially ruled to correspond with the exact indication of the pressure by the hand on the dial.

The portion of chart recorded on should be removed daily, dated and carefully preserved for reference.

The automatic tracing upon the chart should, on no account, be re-traced, as that would effectually destroy its integrity.

Reduced fac-similes of charts actually made are shown in figures 183 and 184.

The speed recording apparatus is specially adapted for factories, mills, etc., where the maintenance of any definite rate of motion is required; and upon railways and steamboats generally, where economy, safety, time and speed, each and all should receive special supervision (as they, alike, demand every possible protection against the results of ignorance, carelessness and recklessness in which the entire community is interested), they are of necessity indispensable. It is obvious that charts automatically traced, which contain evidence of the rate of speed of a train, or the rate of motion of machinery, and whereon the degrees of steam pressure carried is written, and which, furthermore, defines the clock time occupied by any given performance, offer a combination of evidence at once impartial and exceptionally complete and incontrovertible, and must in all future time be of great practical value.

The records may be secured against tampering by a band passing over the glass dome, or may be entirely concealed from view, when such precaution shall be deemed judicious.

These speed records are made by means of a small governor, forming a part of the instrument and shown

attached below the shelf in figure 181. A small grooved pulley is also shown, by which it is driven.

Place the belt in the groove of the pulley (which is four inches in diameter) and so adapt all other pulleys as to secure the desired number of revolutions (or rate of motion), the maintenance of which will result in a uniformly traced horizontal line upon the chart. Any curvatures, either above or below such fixed line, will show the extent of all variations of speed according to the degrees upon the vertical scale and corresponding lines of the chart.

The vertical subdivisions on the chart define the hours, or clock time, and the ruled horizontal lines define each successive five or ten pounds of pressure upon the gauge, from zero up.

By slightly moistening the speed records they become more distinct, and will be rendered indellible. The difference in the color of the tracings will prevent confusion.

Gauge cocks—Each boiler should be provided with at least three; the middle one on the water line, the lower one at least one inch above the crown sheet, or top of flues, and the upper one at any convenient height, according to the construction of the boiler. There are a great variety of gauge cocks in the market to select from.



FIGURE 185.

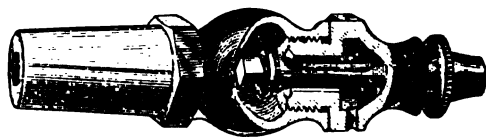


FIGURE 186.

Compression gauge cocks are perhaps the best for portable engines and locomotives; the "Mississippi" gauge cock, shown in figure 185, is an excellent one for stationary boilers. A modification of the latter gauge cock is

made by A. W. Cadman & Co., Pittsburg, Pa., and shown in figure 186.

By reference to the cut it will be seen that the valve and seat is placed at the end most remote from the boiler, thus avoiding the common result of twisting the valve seat out of shape when putting into the boiler. The valve being placed away from the heat of the boiler, it can not be stuck fast by a formation of scale, as is frequently the case. There being no circulation of water in the shank (except when blowing), there can be no danger of its stopping up with sediment. The valve stem being so short it is impossible to bend or break it with the gauge stick.

Glass water gauges—The commonest form of such a gauge is shown in figure 187. In fixing it to the boiler the top of the lower stuffing box gland should be at least an inch above the crown sheet or top of the flues.



FIGURE 187.

This will place the level indicated by this gauge and the lower gauge cock in the same plane. This attachment consists essentially of two connections fitted with valves, one for the steam and one for the water; the latter is further provided with a pet cock to test the lower opening. The glass tube passes through a stuffing box at each end. An ingenious device, shown in figure 188, is by Aug. P. Brown, New York city, which consists of a ball placed in each connection, and of such size as not to prevent the steam and water passing freely into the glass tube; yet, in the event of its breakage, the current of water and steam will carry the balls outward and close the passages leading to the tube. This will allow the insertion of a

new tube, when, by the action of the screw B on the valve A, communication is again made with the boiler.

Fusible plugs should be attached to the crown sheet of all internally fired boilers, and are often attached to the upper side of the flues in externally fired boilers. They consist merely of a brass shell filled with bauxite, or other metal melting below the red heat of iron.

The object of a fusible plug is to melt when the water in the boiler becomes dangerously low, and are placed over the fire box that the contents of the boiler may be emptied into it and put the fire out.

Fusible plugs are often rendered inoperative because they become covered over with scale, which may be of sufficient thickness to withstand the pressure of steam after the metal has been melted below

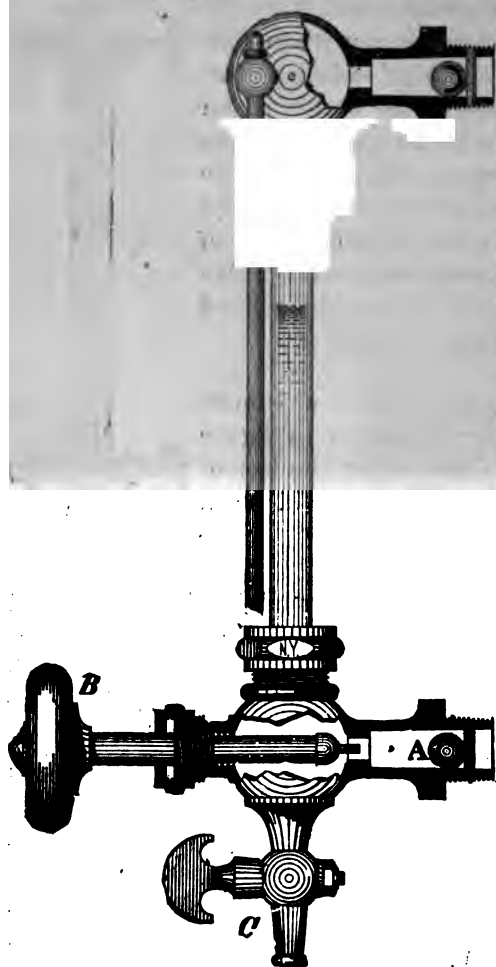


FIGURE 188.

sure of steam after the metal has been melted below

To avoid the possibility of the safety plug becoming inoperative through the accumulation of scale over it, a device for its protection is shown in figure 79, p. 284. The plug is contained in the pipe 3 at a point shown by an enlargement of the pipe about half way up from the bottom of the boiler, and above it a continuation of the same pipe extends upwards beyond the water level, so that as the water never comes in contact with the metal there is no chance of scale ever forming over the metal of the plug. The security against the water falling dangerously low, afforded by the use of the safety plug, has been fully appreciated, but when improperly made or set they may become a source of danger instead of safety.

CHAPTER XVI.

INCRUSTATION AND CORROSION.

Soft and Hard Water—Carbonate of Lime—Sulphates of Lime and Magnesia—Incrustation—Prevention and Removal of Scale—Kemp's Boiler Cleaner—Use of Tannic Acid—Starchy Compounds—Carbonate of Soda—Crude Petroleum—Tannate of Soda—External Corrosion—Internal Corrosion—Pitting of Plates—Grooving.

Feed water may be divided into two distinct classes: *Fresh* and *salt*; as we have nothing to do with marine boilers in this book, the latter will not be considered. Fresh water may be either *soft* or *hard*.

By soft water, is meant pure water; that is, water which, upon evaporation, leaves no mineral residue which had been held in solution. It may contain impurities which are held mechanically, such as sand, mud, etc., which may also be removed mechanically by filtering, or precipitation in tanks where the water is allowed to become quiescent. The localities in which pure or soft water abounds are not numerous. It is the best water for boilers whenever it is practicable to obtain it. Rain water may and often is collected in cisterns for small powers; this is quite practicable and is recommended.

Hard water is to be distinguished from soft in its containing in solution salts of lime, magnesia, iron, etc.; the two former being by far the most common. There are localities in which the sulphates of lime and magnesia predominate, though the carbonates are oftener met with

There are other substances, such as silica, alumina, salt, etc., which are often found in feed water.

Carbonate of lime is well known to us under the names of limestone, marble or chalk. Its presence in feed water may be accounted for in this way: rain water falling upon the surface of the ground is taken up by the soil, and in its passage through it absorbs more or less carbonic acid, there present as a result of organic decay. Cold water dissolves about its own volume of carbonic acid, whatever be the density of the gas with which it is in contact; this property decreases as the temperature of the water increases, so that at the boiling point it is scarcely perceptible.

When water so saturated comes in contact with limestone or marble it dissolves it and we have wells or springs which yield *hard water*. When this water is heated to the boiling point, the carbonic acid is given off and the carbonate of lime remains in the boiler. For a time it is held mechanically in suspension, but gradually attaches itself to the boiler, forming a soft scale by allowing it to dry to the shell after blowing out, the furnace walls being still hot.

Mr. J. M. Allen says, in his annual report* for 1873:

"It has generally been supposed that a deposit in a soft state caused little or no injury to a boiler; but our experience has proved conclusively that the contrary is true. The impalpable powder found in a boiler, when empty and dry, is mainly carbonate of lime, and on account of its lightness it is long held in suspension. When the water, from constant evaporation and little or no blowing, becomes saturated with this material, it is rendered unfit for generating steam on account of the resistance offered to the escape of the steam bubbles, and to the free convection of heat. A deposit of slush or sludge collects on the bottom, around the seams, and in fire box boilers around the furnace sheets and in the water legs. Its presence is detected by leakage at the seams, fractures at the edge of the plates, and in the

*Hartford Steam Boiler Inspection and Insurance Co., J. M. Allen, President, Hartford, Conn.

line of rivets, and by over heating, and consequent depressions of portions of the plates where it rests.

"This action may be better understood by those who have watched the process of making what is known as "hasty pudding." As the corn meal and water begin to boil the difficulty which the steam or vapor generated at the bottom has in escaping is manifested by the sputtering manner in which the surface of the mush is thrown about. If vigorous stirring is not kept up, it burns on the bottom, and acts very much as the slush or sludge from lime does in steam boilers.

"This difficulty is greatly aggravated if grease finds its way into the boilers; the grease appears to combine mechanically with the carbonate of lime and sinks on the plates when the boilers are at rest. It becomes a loose, spongy mass, which is not carried off by the circulation, but, by its contact with the plates, keeps the water from them, and, by offering resistance to the free transmission of heat, causes over heating and burning of plates. Before we had fully investigated this subject, our opinion was, in many instances, where boilers were leaking badly and showed indications of having been burned, that it was caused by the carelessness of the engineer in starting his fire, with no water in the boiler."

What has been said in regard to carbonate of lime is also in the main true of magnesia.

Sulphate of lime is known to nearly every one under its common name, plaster of paris. It is soluble in nearly four hundred parts of water, at a temperature of 95° and almost if not completely insoluble at a temperature of 290°, or slightly more than that corresponding to forty pounds steam pressure. When once found in the boiler, there is no such thing as re-dissolving it by a mere reduction of pressure, as it forms much more rapidly during the day by evaporation than the water will re-dissolve during the night, should the temperature ever get so low as 95°. The formation of scale in a boiler in which sulphate of lime predominates is quite irregular; being more than twice as heavy as water, it can not long remain in suspension, and is found in deposits of varying thickness.

hardness varying according to the substances in combination with it, and the heat to which the whole may have been subjected; and forms, perhaps, the most troublesome scale that the steam user has to contend with.

Carbonate of magnesia will be found in feed water in localities in which magnesian limestone abounds. It is not usually found in any great quantity, as compared with the other salts named. In its behavior in the boiler, it is not unlike carbonate of lime at similar temperatures.

There are a number of other substances which act in a manner analogous to those already referred to, but as they are in general so small in quantity, when compared with the others, they need not here be particularly described.

The impurities in feed water, when consisting of salts of lime and magnesia, produce *incrustation*; when an excess of acid is contained in the water, *corrosion* takes place.

Incrustation, when allowed to form in any boiler, has the effect to reduce its steaming capacity and also induces over heating of the plates, by reason of its being a non-conductor of heat. Its presence also prevents a satisfactory internal examination of a boiler, as it covers the joints and other portions which should be laid bare to make the inspection thorough.

Many attempts have been made to calculate the loss of heat by the accumulation of scale. The results show great loss, but exactly how much is not entirely known; it is placed by different observers as follows:

- $\frac{1}{16}$ inch thick requires an increase of 15 per cent in fuel.
- $\frac{1}{8}$ inch thick requires an increase of 30 to 60 per cent in fuel.
- $\frac{1}{4}$ inch thick requires an increase of 60 to 150 per cent in fuel.

This last line is given for what it is worth.

The prevention and removal of incrustation is a subject which interests every one having a boiler fed with hard water. The usual means of prevention and removal are, by blowing off; the use of chemical agencies which render the impurities more soluble; the use of some mechanical device, fitted to the interior of the boiler, which will collect the deposit and which may then be removed, cleaned and replaced.

Blowing off is the easiest and readiest method of getting rid of surface impurities which will prevent the free escape of steam at the surface of the water. There are many devices for this purpose; the one described below is said to yield excellent results by those who have them in use.

Kemp's boiler cleaner, as manufactured by James F. Hotchkiss, Bay City, Mich., is shown in figure 189, as attached to the boiler when in use.

A is a box or reservoir located above or upon the arch wall of the boiler. In marine boilers the reservoir may be suspended from the deck frame above; from this reservoir three pipes extend; the first pipe, B, enters the rear part of the top sheet of the boiler or generator, and is connected with a horizontal pipe, which is adjusted a little below the water line. At either end of this horizontal pipe is an enlarged mouth, C, partly submerged, but extending a little above the surface of the water—the mouths being of a diameter to allow several inches variation in the water line. The second pipe, D, leading from the reservoir A, enters the other end of the boiler, in similar manner, terminating below the water surface.

When the boiler is heated, a constant current of water is immediately established through the bell mouth C, and pipe B, filling the reservoir A, and, cooling to a certain extent, it returns to the boiler by the pipe D. It will be

observed that the up flow pipe is placed about midway between the fire bridge and the back end of the boiler, at a point where the water is presumably hottest. On the other hand, the down flow pipe enters the front or cooler portion of the water, and, while the water may rise and fall in the boiler to any moderate extent, the enlarged mouths, C, will constantly maintain a current free from steam, from the surface.

As the sediment and impurities are chiefly separated from the water by ebullition in that part of the boiler where the horizontal pipe C is located, they are immediately drawn in by the current and carried into the reservoir A; here, the current, weakened by expansion, can support the impurities no longer, and they settle in the reservoir, and are retained, until blown off through the third pipe E, as seen in the engraving. The reservoir may be located at any desired point above the level of the water line, as most convenient, and occupies no appreciable room. It usually holds about three gallons of water.

When the boiler is in use the stop cocks should always be left open.

To wash the reservoir out, open cock E for about half a minute once each day, or as often as necessary. This is simply all the attention required in a general way. By placing a vessel under the blow off pipe, the amount of deposits can be easily ascertained.

In severe cold weather, where the boiler is exposed and allowed to stand unused a day or more at a time, shut the



FIGURE 189.

stop cocks D B, and open cock E, leaving the reservoir empty; but so long as the water is warm in the boiler, it will circulate through the reservoir and keep it from freezing.

The use of chemical agents seems to be a favorite one for the prevention or removal of scale. There are hundreds of "boiler compounds," some of them of surpassing excellence, others perfectly useless, if not positively hurtful. Nearly all compounds for this purpose have either tannic acid or soda as the active agent. Vegetable matter does not, as a general thing, act injuriously on the plates and if it contains any considerable quantity of tannic acid, it may prove of great value in arresting or preventing incrustation; and for this reason caoutchouc (crude india rubber) nutgalls, logwood, hemlock, mahogany, etc., are often employed as scale preventives. The chemical action of the tannic acid is to decompose the carbonates in the water, and thus to form a tannate of lime, instead of a carbonate, and in the same manner for carbonate of magnesia. Tannates of lime and magnesia are not soluble, and being of light specific gravity, are held mechanically in suspension by the circulation of the water. These particles of tannate of lime or magnesia floating in the water do not have a tendency to unite to form masses by their adhesion, and may easily be blown out of the boiler with the water. This chemical reaction does not occur in water containing sulphate of lime, and for this reason an analysis of the water should be had before using any compounds having tannic acid as the principal ingredient.

Molasses, potatoes, vinegar, etc., etc., have found their way into boilers as preventives. The latter containing acetic acid, decomposes the carbonates of lime and magnesia, forming acetates, which, being soluble, are kept in solution and do not form scale. There is danger, how-

that an excess of free acid will act injuriously on the plates. In regard to potatoes or any starchy compounds, they may and often do prove serviceable. Their action seems to be mechanical, and to envelope the solid particles of lime and prevent adhesion. Scale has not only been prevented, but actually removed, by simply using potatoes in the boiler. It should be borne in mind that starchy ingredients, of whatever kind, have a tendency to produce frothing, and thus to deceive the fireman as to the correct water level. These have little or no action on sulphate of lime, but are to be confined to water having carbonates only.

Carbonate of soda, caustic soda, potash and other fixed alkalies have been used with varying results. These will decompose sulphate of lime and form sulphates of soda or potash, which will be retained in solution and the carbonate of lime precipitated.

Alkalies do not injuriously attack the plates of the boiler, and may often prove beneficial in neutralizing the effect of free acids present in the water.

Petroleum has been used with marked results. Mr. Allen says, in the same report already quoted from,

"We have a specimen of scale in this office nearly one and a half inches thick, that was removed from a boiler in the west by crude petroleum, or what is known as unrefined, black, earth oil. I am aware that there is great prejudice against using anything of the kind in steam boilers, but earth oils are very different from animal oils. They are very volatile, and in an experience of several years where hundreds of boilers have been treated with it, we have found no injury to plates or tubes, and the boilers have been kept free from scale. Petroleum works better where sulphate of lime predominates, than in waters impregnated with carbonate of lime. We would not advise it in connection with the latter. I desire to impress upon all persons the importance of careful attention to their boilers when solvents of scale or purgers are used. It often happens that scale is thrown off and allowed to accumulate on the bottom of the boiler, and from want of attention, not being removed, the boiler becomes

ly or quite ruined. If a purger is used, the boiler opened and as often thoroughly cleaned."

Soda is a compound which, it is claimed, decomposes the carbonate and sulphate of lime in solution. This compound was finally decided upon after a long chemical research, by Jos. G. Rogers, M.D., and. Its action may be described thus: Tannate of soda decomposes the carbonates of lime and magnesia as they enter, tannates being precipitated in a light, flocculent, amorphous form, so that they do not subside at all in the boiler, but are retained in suspension by the boiling currents until they find their way into the mud receiver, where they settle into a loose, mushy mass, which may be easily blown out from time to time. The carbonate of soda, formed in the reaction, is retained in solution, becoming a bicarbonate by appropriation of the free carbonic acid in the water. This decomposes the sulphate of lime, the resulting sulphate of soda being retained in solution, and the carbonate of lime being acted upon by fresh portions of the tannate of soda as above. The constant presence of the alkali protects the iron from all action, either of the carbonic or tannic acids. The same reaction takes place between the tannate of soda and the already existing scale, with like results, but more slowly, some weeks being generally required, in practice, in removing the deposit, if it exists in any considerable quantity.

Zinc has been used with some success with water containing bicarbonate of lime; it has no effect on sulphate of lime. The disappearance of zinc in the boiler is no indication that it is preventing scale, as it may be reduced by galvanic action.

This portion of the chapter might be almost indefinitely extended, and be of no practical use when completed.

The writer has given in brief outline the action of the commonest and perhaps the best anti-incrustators. One thing must be done before any one of the several substances named can be recommended; that is, an analysis of the water, showing whether it contains carbonates, sulphates or acids, which of each, and in what quantities. Then and only then, can an intelligent recommendation be given. The writer's advice to boiler owners is that, no preparation be bought or used until after such analysis by a competent expert or chemist.

External corrosion is frequently caused by the exposure of the shell of the boiler to the weather. It often occurs that boilers have no other protection than simply a loose board roof which, even in ordinary rain storms, leak at every joint. If the boilers were always under steam the bad consequences would be comparatively light, but the greater mischief occurs when the boilers are cold. Whenever rust appears on the surface of a boiler it means loss of iron, loss of strength, and consequently is less able to withstand high pressure. The danger is increased if the action of the rust be confined to certain portions of the boiler and continuous deterioration be going on; this is likely to occur along the line of brick work, in externally fired boilers, near the water line. In exposed situations this rate of corrosion may amount to one-sixteenth inch in a single year. This is perhaps exceptional; but a boiler would soon be rendered worthless if only half that waste of iron was going on and which is not at all exceptional.

Another source of corrosion is that which proceeds from leaky joints, either from the riveted seams, man or hand holes, or from imperfectly fitted attachments. When the leak occurs around a rivet a new one should be put in; if in the seam, it should be re-calked inside and out. The gaskets used between the shell and hand, or man hole

plates, are often so imperfectly fitted that it is the exception to find them perfectly tight. A gasket of vulcanized rubber, say three-sixteenths to one-fourth inch thick, is recommended rather than a plaited one made of hemp, when used with high pressures. A gasket recently

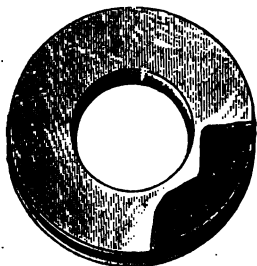


FIGURE 190.

brought to the attention of the writer is shown in figure 190, and is the invention of Mr. C. S. Stoy, Butler, Indiana. It consists of a thin copper shell, filled with packing, as shown. There is little doubt that it will make an excellent joint and may be used over and over again. But whatever packing may be used the joint must be tight, and a leak, however trivial around a boiler, should be immediately repaired.

Internal corrosion—This wasting of the plates is doubtless caused, in the main, by the action of acids in the water. It has also been attributed to galvanic action. A noticeable thing in connection with internal corrosion is its want of uniformity: its appearance is not unlike ordinary rusting and is not difficult to detect. The following extract is from Mr. Allen's report for 1875, and agrees with the writer's own observations. I am also indebted to Mr. Allen for the accompanying engravings:

"The work of corrosion is insidious, whether it is external or internal. A boiler that is set in brick work may leak at the seams, and corrode the plates adjoining, and yet there may be no indication of danger. So, by the use of impure water, a very dangerous process may be going on inside the boiler. In boilers covered more or less with scale its presence is often detected by red streaks where the scale is cracked. It attacks the edges of plates at the joints, and around the rivet heads. Sometimes it will attack two boilers working side by side. One will be corroded in the front part, and the other

in the back part. Sometimes different sheets in the same boiler will be corroded, while others remain intact. Again, boilers will be found in what is known as a *pitted* condition. This is manifested by small spots in close contact, being eaten into the sheet. It looks like a pock marked face and is sometimes confluent; and what is strange about this is, that often certain sheets in the boiler will be attacked while others will remain clean and smooth, and the iron will bear the



FIGURE 191. SECTION ON A B.

same brand on each plate. It is well known that iron ore, even from the same mine, is not always chemically the same; certain impurities will be found in some places which do not exist in others. And in the manufacture of boiler iron there is no doubt but that the sheets are chemically slightly different; hence, when the boiler is constructed the presence of acids in water may excite galvanic action. This would account for the different manner in which boilers are affected. The following figure will illustrate the effects of corrosion:

"This was discovered by inspection. The outer and inner side of the sheet is shown in the drawing; also a cross section. The hole in the center of the sheet was made by the inspector's chisel. The iron was little thicker than paper; the piece of plate can be seen in this office.

Figure 192 represents a portion of the inner plate of a water leg of a locomotive boiler. Corrosion attacked the plate around the stay bolts, as represented by the radiating dark lines. The other end of the stay bolts was eaten nearly off. We judge from appearances that in tapping out the holes for the stay bolts, a strain was brought to bear which disturbed the fiber of the iron, or perhaps I should say the skin of the iron; imperceptibly, however, to the casual observer.

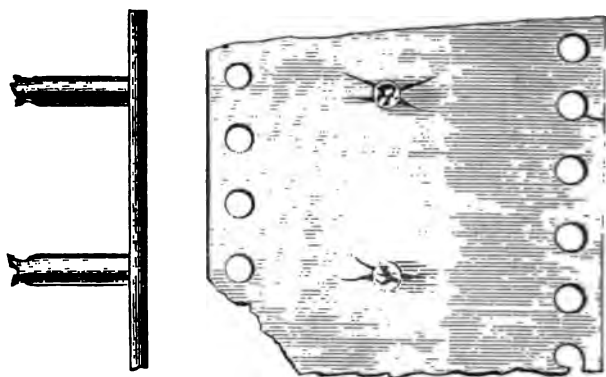


FIGURE 192.

"The difficulty was further aggravated by the unequal expansion and contraction of the two sides of the water leg. The inner sheet forming the side of the fire box was subjected to greater heat, and this continual, though imperceptible action assisted in increasing the difficulty.

"Impure water found this disturbed point the most open to attack, and the result is as we find it here. The furrows are eaten in quite deep, and it looks like the work of a tool."

Pitting.—When internal corrosion occurs in isolated spots it is called pitting. This generally occurs near the joints of the plates, but not unfrequently directly on their faces. It is not uncommon to find pitting up in the steam dome, and from the fact that it is as likely to occur away from as in contact with the water, it is now generally believed to be due to galvanic action.

Figure 193 is loaned by Mr. Allen to show the peculiar corrosive effects found in a boiler fed by *swamp water*, and is engraved from a sample now in the office of the Hartford Steam Boiler Insurance and Inspection Company.

Grooving—There is not a well defined and satisfactory explanation which will wholly account for this destructive

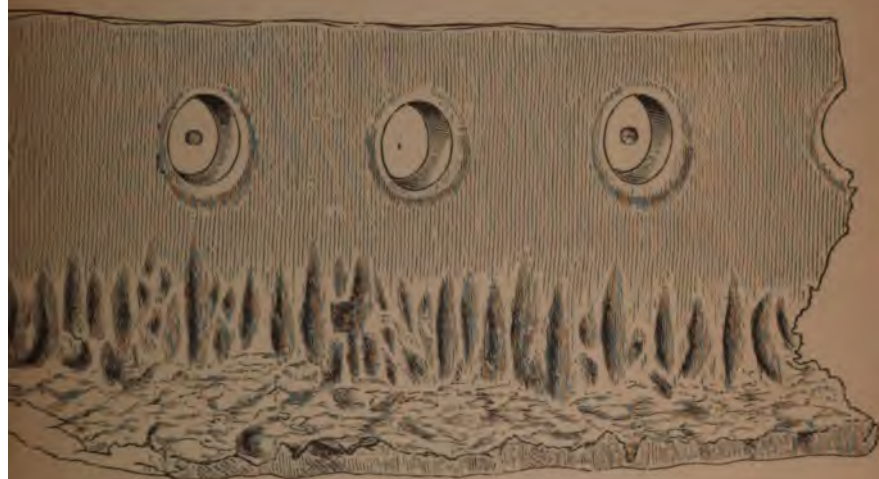
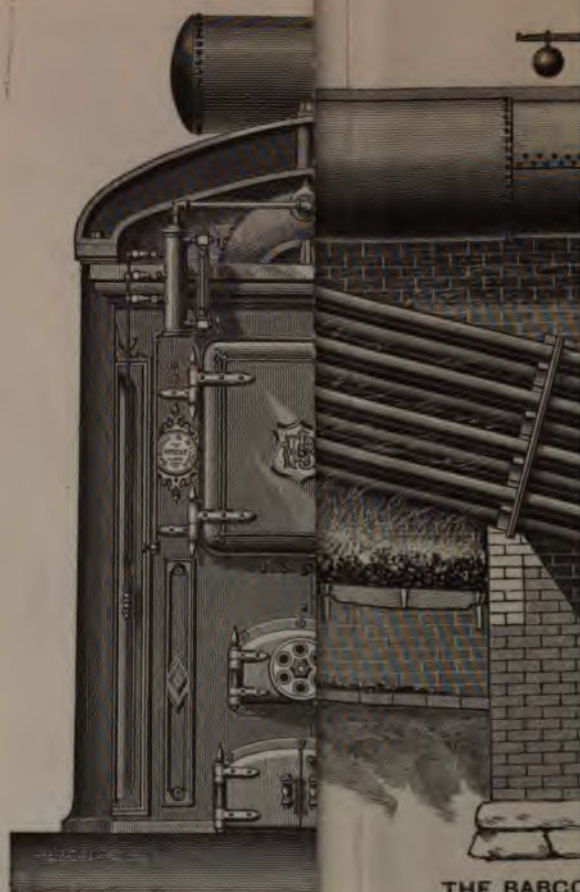


FIGURE 193.

action in boilers. It is believed, however, that it is caused by the constant changes of form which take place in a boiler by the alterations of pressure, and thus induce a hinging or buckling action of the plates, particularly along the lines of riveted joints. In the ordinary method of making boilers, it is impossible to make a shell perfectly round, and when such a boiler is subjected to steam pressure the tendency is to make it a true cylinder, and this is the cause of the buckling or hinging above referred to. If the plates are made of fibrous iron, they are loosened every time this occurs, and it is greatly aggravated by the

continued changes of temperature to which the whole is exposed. The iron being less firm at this point than elsewhere, corrosion becomes all the more easy and certain, and is further assisted by imperfect or too rigid bracing at certain points, and too slack at others. It is not now, as was formerly, believed to be due to galvanic action.





THE BABCO



CHAPTER XVII.

SECTIONAL BOILERS.

the Wilcox Boiler—The Root Boiler—Kelley's Boiler—The
the Boiler.

Sectional boilers are not as yet common property, and we can only refer in a general way to the details of construction as practiced by the several makers, whose details will be described. No attempt can be made in a single chapter to trace the development of sectional boilers, to describe all those now in the market; three or four examples will be given to illustrate the present practice of boiler manufacturers.

The *Rock & Wilcox boiler* is shown in front elevation in figure 194, in longitudinal sectional elevation in figure 195; these cross sectional elevations in figure 196; these longitudinal sections, for convenience of reference, are printed on a separate sheet.

The boiler is composed principally of lap welded horizontal tubes four inches in diameter, arranged in longitudinal rows of seven or eight tubes in each. These sections are inclined at an angle of about 15° , as shown in the longitudinal section.

The sections are connected with each other, and with the mud drum at the bottom and rear of the boiler, also by vertical passages at each end, with the horizontal steam and water drums shown in the cross sectional elevation. The water fills all the tubes and runs the way up and into the steam and water drums.

The end connections are in one piece for each vertical row of tubes; these tubes do not lie one above the other in a vertical line, but are staggered so as to receive heat either by radiation or direct impact by the flow of heated gases upward through the spaces between them. These tubes are not threaded, but secured to the end connections by the use of an expander in a manner similar to that in which tubes are fixed in an ordinary tubular boiler. The connections between the mud drum and the steam and water drum are made in the same manner, and thus dispensing entirely with bolted joints and packing. By this arrangement are secured freedom from strains induced by unequal expansion, and a means of rapid and thorough circulation of water. The water inside of the tubes when heated has a tendency to rise toward the higher end, and flows upward and into the steam and water drum. The steam is here given off, if the water is of sufficiently high temperature. The back connection secures a downward current, and thus a continuous circulation is established, preventing the evils arising from the destructive strains consequent upon unequal temperatures. This rapid circulation also prevents, in a measure, the formation of scale upon the heating surfaces, sweeping the particles away and depositing them in the mud drum, from which they may be blown out.

The provision for cleaning the boiler, both internally and externally, is quite complete. Hand holes opposite each end of each tube, man holes in the drums, and a bonnet to the mud drum, permit access to all parts of the interior, while side doors admit of the removal of accumulated dust and ashes from the exterior of the heating surfaces, either by blowing, brushing, or any other well known means.

The proportions of this boiler were adopted after numerous experiments with boilers of varying capacity.

and experience has established that it can be driven to the utmost, and still be free from the objections always attaching to boilers of small capacity—carrying a steady water level and steam pressure, and always furnishing dry steam.

The cubical capacity of this boiler, per horse power, is equal to that of the best practice in tubular boilers of the ordinary construction. The fire surface being of the most effective character, these boilers will, with good fuel and a reasonably economical engine, greatly exceed their nominal power, though it is seldom economy to work a boiler above its nominal power. The space occupied by this boiler and setting is equal to about two-thirds that of the same power in tubular boilers.

The following is an abstract of a test of a Babcock & Wilcox boiler, by Charles E. Emery, C.E., New York city.

This test was made in February, 1879, at the Raritan Woolen Mills, Raritan, N. J. There were two boilers in use, containing 4,080 square feet of heating surface, and 103 square feet of grate surface, the capacity of the two boilers being rated jointly, by the makers, at 360 H.P.

The experiment commenced at 6.01 A. M., and closed at 6.38 P. M. In starting, steam was raised by spreading the banked fires left from the previous day. When the pressure reached 80 pounds the fire was hauled, all refuse removed, and fires started anew with wood, which in the calculation has been considered equal in calorific value to $\frac{4}{10}$ its weight of coal. The fires were maintained with coal during the day, finally hauled, allowed to cool, the combustible portion deducted from the coal charged, and the refuse weighed separately. The experiment was closed when the boilers stopped making steam at 80 pounds pressure, with water in the glass gauges at same height as at starting.

During the trial, all the coal consumed was weighed in an iron wheelbarrow, balanced when empty by a fixed

tubes. Steam is collected from the tubes into the steam drum which is placed over the top of the boiler, as the form of construction affords ready facility for the renewal of tubes.

The water level should not be carried too high if there is a severe draft on the boiler, as it is likely to induce priming. When steam is generated in the tubes, it rises to the steam drum through the triangular elbows (return bends and perhaps be nearer correct), seen at the front end of the boiler. In passing through the bends the current is broken, and if any water is mingled with the steam it is thrown back into each tube.

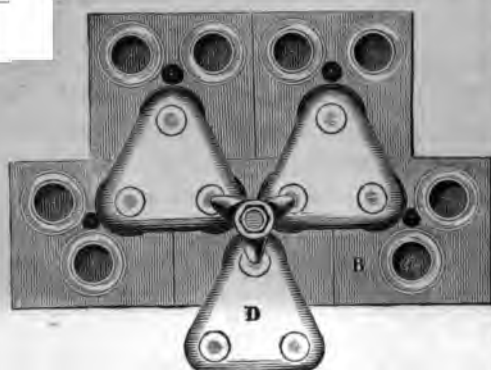


FIGURE 201.

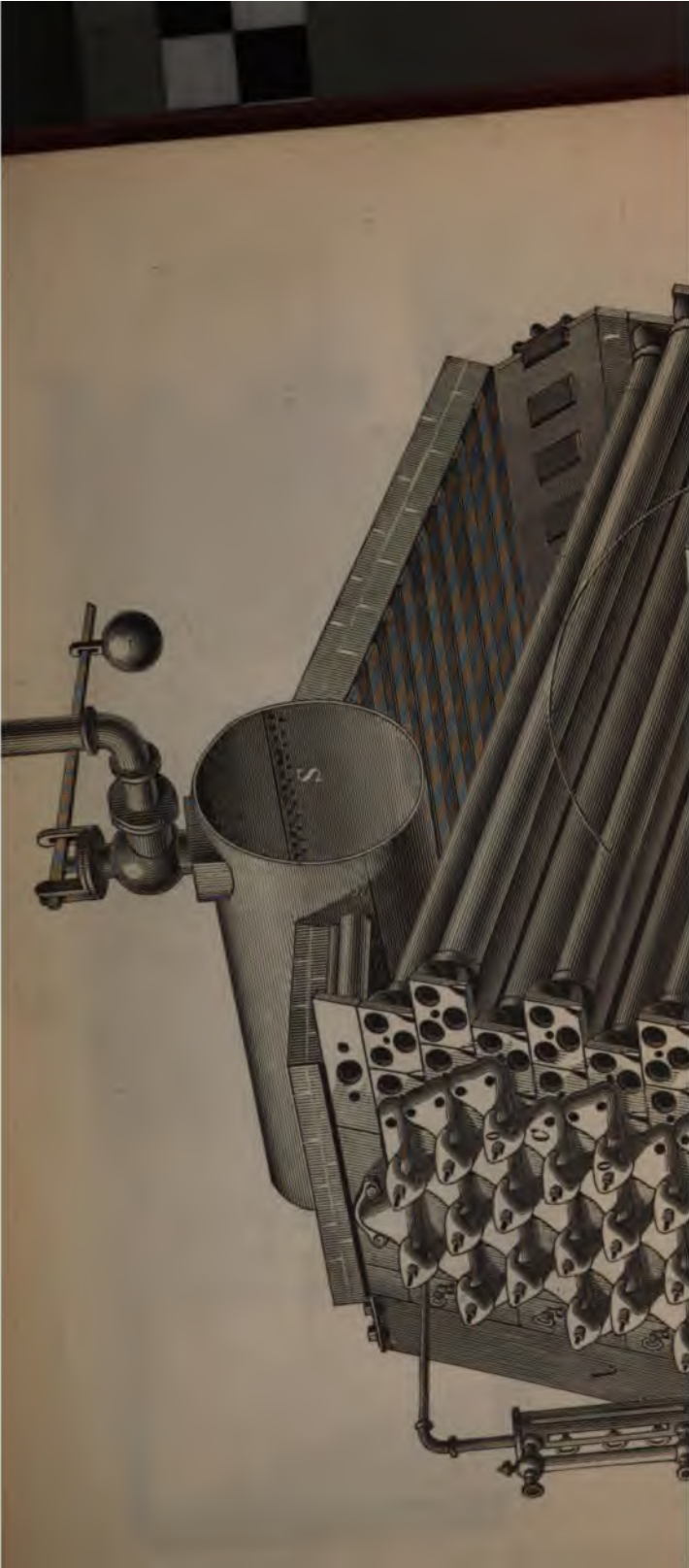
This breaking and reversal of the current to prevent priming is now generally recognized as

the correct way to do it, and no doubt is the explanation of the remarkable freedom which this boiler has from this troublesome and dangerous occurrence.

If the demand upon the boiler is constant, a steam drum need not be supplied, but when the requirements are irregular, it is then perhaps best to have it.

The grates may be of any of the common or oscillating varieties now in the market.

The course of the products of combustion are clearly shown by the direction of the arrows. The tubes have what the makers call "bridge wall blocks," which are shown at A. These are built up to any required height





1. The first part of the document is a list of names and addresses of the members of the committee.

2.

3.

4. The second part of the document is a list of names and addresses of the members of the committee.

to insure every part of the tubes being in contact with the heated gases.

The following test was made at the Centennial Exhibition, Philadelphia, Pa.:

Heating surface, square feet.....	1,590.
Grate surface, square feet.....	42.
Coal used (anthracite), pounds.....	3,053.9
Ashes, pounds.....	320.2
Steam pressure, pounds.....	69.94
Temperature of feed water, degrees.....	64.59
Water evaporated by calorimeter tests, pounds.....	27,146.69
Water evaporated per one pound of coal from temperature of feed, in pounds.....	8.89
Water evaporated per one pound of coal from and at 212°, pounds.....	10.35
Water evaporated per one pound of combustible from temperature of feed, pounds.....	9.93
Water evaporated per one pound of combustible from and at 212°, pounds.....	11.565
Water evaporated per square feet of heating surface from temperature of feed, pounds.....	2.22
Water evaporated per square feet of heating surface from and at 212°, pounds.....	2.48

Kelley's sectional boiler, by William E. Kelley, New Brunswick, N. J., is shown in sectional elevation in figure 203, and in detail showing the manner of securing the tubes and the circulation of the water through the boiler, in figure 202.

The tubes in this boiler are 3 inches in diameter, and screwed into the vertical chamber, as shown in the detailed engraving.

These tubes, with the exception of those in the upper row, are inclined at an angle of about one to eight, and connected at one end only, and that at the vertical chamber.

The tubes are therefore left free to expand separately without affecting others, and in like manner may be removed for examination or repair. A cap is placed at the back

end to close each tube. Inside of these tubes are placed partition plates, as also shown.

The inclined tubes are always full of water, the water line of the boiler being at W. L. The heat from the fuel

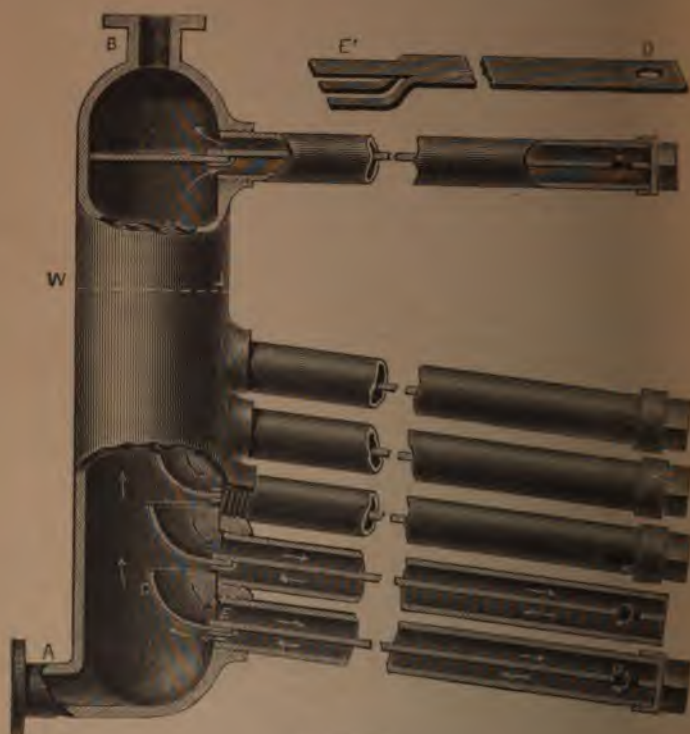
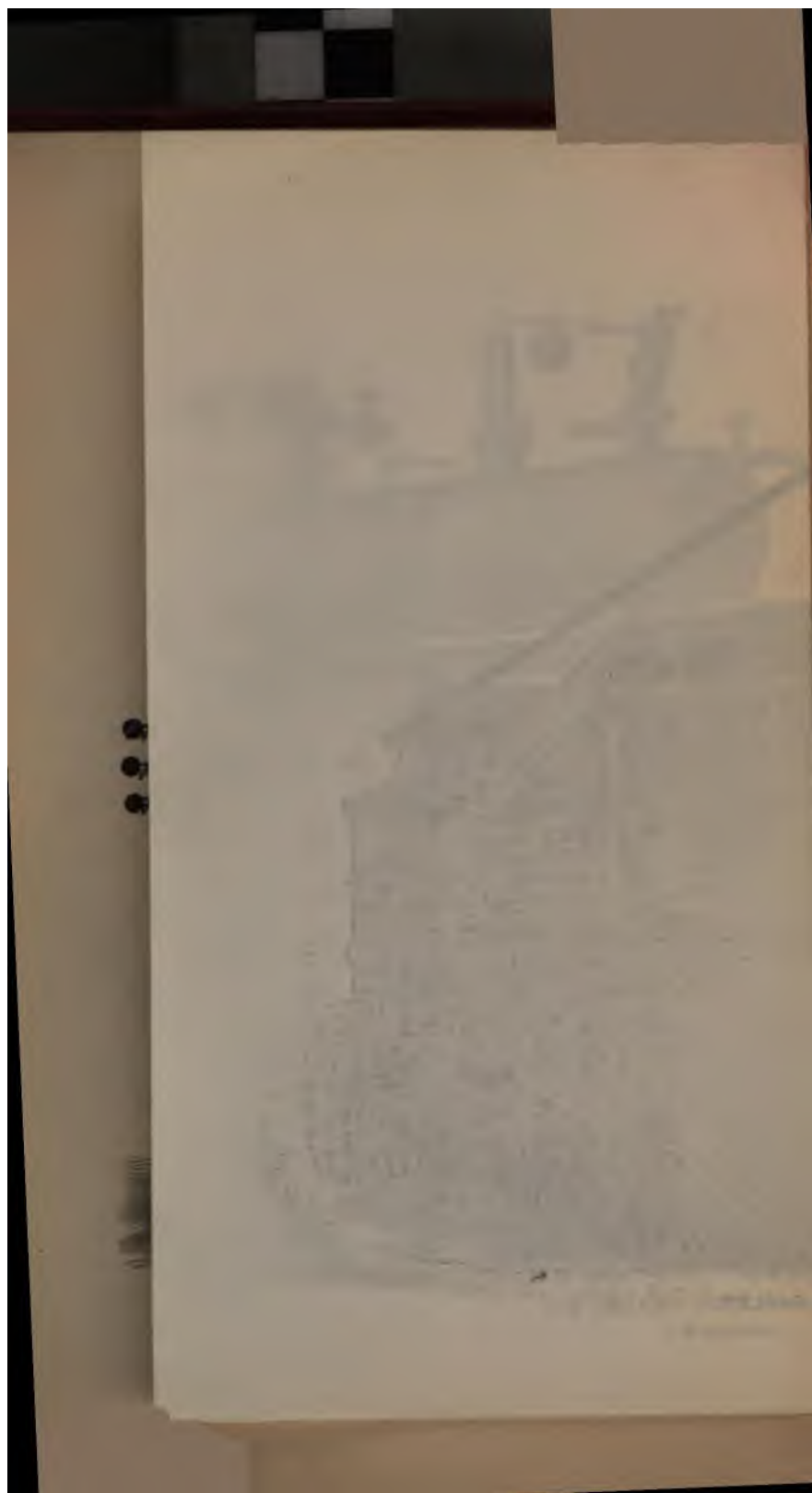


FIGURE 202.

on the grate in rising first comes in contact with the lower half of the inclined tube, the upper half of the tube being in a measure shielded or protected from the direct heat or flame by the lower half; consequently the greatest amount of steam will be generated from the surface of the lower half of the tube. The steam thus made would rise to the upper side of the tube, were it not intercepted by the par-



1. The first part of the paper is devoted to the study of the

2. The second part of the paper is devoted to the study of the

tition plate; this causes the steam to move along the under side of the partition plate, and along the outside of the pocket in the front chamber, and thence into the dome, first passing through the horizontal pipe, as will be hereafter explained. The upper half of the tube, as before stated, will be less exposed to the direct action of the fire; hence the water will flow down the coolest part of the tube, and through an opening, D, in the rear end of the partition plate, and thence up through the lower half of the tube, as before stated, the circulation being accelerated by the volume of steam that is seeking an exit from the lower half of the tube into the front chamber. The pockets in the front chamber tend to keep the downward and upward currents separate. The arrows on the cut indicate the direction of the circulation.

The free exit of the steam from the front chamber into the dome is obstructed by a partition running entirely across the chamber, near the top and above the water line, W. L., and the steam is compelled to pass along under the partition in the horizontal pipe, and through the opening in said partition, and then along over it, through the upper half of the tube into the chamber and dome; as the tubes are in the heat and above the water line, the steam is made very dry, and all moisture and water that would otherwise be carried out of the boiler is converted into steam in passing through the horizontal tubes.

The following test was made at Philadelphia, during the Centennial Exhibition :

Heating surface, square feet.....	662.
Grate surface, square feet.....	27.5
Coal used, anthracite, pounds.....	2,380.95
Ashes, pounds.....	204.5
Steam pressure, pounds.....	69.95
Temperature of feed water, degrees.....	66.95
Water evaporated by corrected calorimeter tests, pounds.....	18,710.53

A TREATISE ON STEAM BOILERS.

Evaporated per one pound of coal from temperature of feed, pounds.....	7.858
Evaporated per one pound of coal from and at 212°, pounds.....	9.139
Evaporated per one pound of combustible temperature of feed, pounds.....	8.636
Evaporated per one pound of combustible and at 212°, pounds.....	10.94
Evaporated per square foot of heating sur- face from temperature of feed, pounds.....	3.52
Evaporated per square foot of heating sur- face from and at 212°, pounds.....	4.13

The *Firmenich boiler*, by J. C. & F. Firmenich, Buffalo, N. Y., is shown in sectional elevation in figure 204.

This boiler consists of two partially cylindrical wrought iron shells at the bottom, separated sufficiently to admit the requisite width of grate. From the upper and flat side of these lower cylinders or mud drums, pipes extend upward and are connected to similar drums at the top.

Surmounting these two upper drums is still another, having suitable connections with the two lower ones, and acts as the steam drum or reservoir for the boiler.

The lower drums vary in size from twelve to twenty-four inches, and the upper steam and water drums, from twenty to thirty-six inches diameter; the lengths varying according to the size of the boiler. The vertically inclined heating tubes are from two to three inches in diameter, the latter size being used in all boilers over twenty-five horse power. This boiler offers good facilities for external and internal examination. Figure 204 is a cross sectional elevation, showing the arrangement of drums and tubes.

The following figures are taken from the report of the economy trials at Philadelphia during the Centennial Exhibition:

Heating surface, square feet.....	1,678.88
Grate surface, square feet.....	15.84
Coal used (anthracite), pounds.....	1,482.35
Ashes, pounds.....	153.25
Steam pressure, pounds.....	70.06
Temperature of feed water, degrees..	68.94
Water evaporated, calorimeter tests, pounds.....	13,233.6
Water evaporated per one pound of coal from temperature of feed, in pounds.....	8.93
Water evaporated per one pound of coal from and at 212°, pounds.....	10.34
Water evaporated per one pound of combustible from temperature of feed, pounds.....	9.95
Water evaporated per one pound of combustible from and at 212°, pounds.....	11.63
Water evaporated per square foot of heating surface from temperature of feed, pounds.....	1.33
Water evaporated per square foot of heating surface from and at 212°, pounds.....	1.77

The tubes in this boiler being nearly vertical, prevents the accumulation of soot or ashes on them.

The combustion chamber is of unusual dimensions, and by properly arranging for the admission of air the combustion should be complete and a very high temperature maintained at all times.

Those who have this boiler in use, speak well of it and claim a saving in fuel over the same evaporation with ordinary boilers.



FIGURE 204.

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